Reconstruction of the Halifax High Service Reservoir

By R. M. Doull and J. D. Kline

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HALIFAX, N.S., draws its water supply from a system of lakes located a few miles outside the city. Due to the differences in elevation within the city, the water works system forms two services—low and high. Water for the low service area is transmitted through 24- and 27-in. cast-iron mains to the city by gravity flow, aided by a booster pumping station at the outskirts. Water for the high service area flows through a 15-in. cast-iron main entirely by gravity to the higher elevations of the city.

In 1913 a reservoir was built to provide storage capacity within the city and to improve pressure conditions in the higher elevations. During recent years, the 15-in. main has not had the capacity to supply the high service requirements, and water has

had to be pumped from the 27-in. low service main to the reservoir which floats on the high service system.

The reservoir was constructed in the northern part of the city on the highest elevation available—a spot called "Hungry Hill." At that time this section of the city was only partly developed and there was little protection from the elements. In November 1917 the Halifax explosion occurred a scant half mile away, blasting every tree and house from this area, affording the reservoir less protection than ever. Again in 1945 the ammunition magazines in Bedford, a few miles to the north, caught fire and shook the city with a series of violent explosions. Although these two catastrophes wrecked great sections of the city, little apparent damage was suffered by the

reservoir as a direct result. Time and natural weathering, however, were not as kind.

Construction of Reservoir

The reservoir was designed as a massive concrete structure, 160 ft. id. and 25 ft. deep, with a capacity of $3\frac{1}{2}$ mil.gal. The foundations were carried down about 8 ft. below grade and heavily reinforced. The floor consisted of a 6-in. slab poured with the footings over a compacted fill, and another 6-in. reinforced slab, overlying this, poured in place after the walls and columns were built.

The walls were 3 ft. thick at the bottom, tapering to 18 in. at the top. They were poured in approximately 3-ft. lifts, with a $\frac{3}{8}$- × 4-in. water bar in each joint, and contained a mass of reinforcing steel in two concentric layers, 4–6 in. behind the inside and outside faces. The horizontal steel was elaborately supported by vertical structural frames, each bar resting in chairs bolted to the frame. The vertical steel was wired to the horizontal bars on the side towards the center of the wall. The close spacing of the steel and the structural frames contributed to a very material extent to the eventual failure of the walls. An idea of the quantity of steel employed may be obtained from the fact that, in the bottom 11 ft. of the wall, there were 88 $1\frac{1}{4}$-in. diameter horizontal bars, in addition to the vertical steel, frames, struts and water bars.

The roof was built as a very flat cone with barely enough slope to provide for runoff of rain and melting snow. The slab was 4 in. thick and was carried on a series of radial concrete girders, 12 × 20 in., and cross-beams of various sizes and spans. This whole structure was in turn supported by 53 18 × 18-in. concrete columns and by the walls themselves. Each girder was haunched into the walls at the outer ends and attached by heavy caps to the columns.

Very little maintenance work was done to the reservoir after completion to correct the troubles that appeared. Some poured-in-place concrete patches were placed on the exterior walls, but they were not very effective, and only served to cover up the real trouble temporarily.

Condition Before Repair

In 1945 the Public Service Commission took over the administration and operation of the Halifax water system, and the reservoir came up for critical inspection. The commission's engineers uncovered the following defects:

1. The roof was near the point of complete failure; portions had already fallen into the reservoir and in places the slab had pulled away from the wall.

2. Most of the supporting beams and girders had failed completely in shear (Fig. 1).

3. The columns appeared in fairly good condition, except for fractures in a number of the caps.

4. Fifteen ft. above the floor, a band about 4 ft. high, extending completely around the inside wall, was so badly eroded that the interior layer of reinforcing was exposed—a condition probably aggravated by ice action, since the area was located at about normal water level. It was also evident that construction joints were open in many places.

5. The floor could not be inspected, as no provision had ever been made to drain the reservoir completely. About 10 in. of slime and muck covered the floor under the water that remained.

6. Fully 50 per cent of the exterior wall area above grade was heavily spalled. Large sections of the wall had fallen off in blocks 5 to 6 in. thick. Much of the reinforcing steel was exposed and had fallen to the ground or was bent out at various angles. The concrete which had been exposed was soft and in places resembled piles of loose gravel held in place by the reinforcing. There was no apparent seepage of water through the walls (Fig. 2, 3).

7. The connecting gatehouse was generally in the same condition as the rest of the structure, but spalling did not appear to have penetrated so deeply.

8. Actual test measurements disclosed that, in spite of the bad conditions, very little water was being lost. Test pits around the outside wall confirmed this and showed almost no disintegration in the wall below grade. Reasons for the disintegration were fairly clear. The beams and girders probably failed in shear. Frost action accounted for the deterioration of the walls. Water gradually seeped through the construction joints, and, through repeated freezing and thawing, set up local pressures which were sufficient to knock off sections of the wall. Some of the reinforcing bars were bonded to this outside shell and were torn away and bent as the shell broke off.

Planning Repairs

The commission was faced with the problem of either repairing the old reservoir or demolishing it and building a new structure. Demolition was necessary if new construction was decided upon, for no other site was available. Time, too, was an essential factor, as the reservoir is required for the efficient operation of the system. Expert and other opinions were expressed on the proper course to follow.

Finally the commission issued a set of general specifications, photographs and plans of the structure and called for competitive bids. Each contractor was requested to submit his own detail drawings, an outline of the method he proposed to follow, a complete specification and guaranteed time schedule.

After bids were reviewed, the Canada Gunite Co. was awarded the contract. The tender submitted by this contracting firm was more than $20,000 less than the next lower bid, and, in addition to this important saving, there were a number of original features in the company's specifications:

1. The capacity of the reservoir was to be increased 500,000 gal., and the head to be raised 4 ft.

2. Repairs were to be made by the gunite process.

3. A new pre-stressed concrete dome roof was to replace the old roof.

With the drawings and specifications approved, work started May 15, 1946. The completion date was Nov. 15.

Methods and Equipment

The work fell naturally into three distinct phases: (1) demolition of the old roof structure; (2) restoration of the old concrete, and (3) the construction of the new dome roof. Each of these sections will be discussed separately, although they were carried out together as part of one operation in the field.

The equipment set up played an important part in the method specified for the job. The main power used was compressed air. This was furnished by two 365-cfm. air compressors driven through V-belts by 75-hp. electric motors. Air lines were piped to various points on the job to operate the
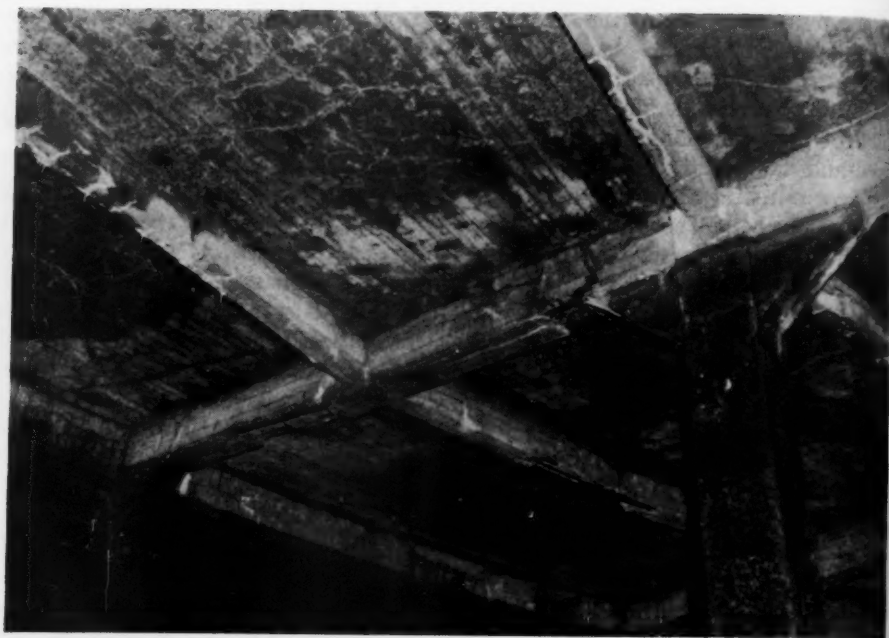
Fig. 1. Fractured Beam and Girders in Underside of Roof Slab

Fig. 2. Spalling of Reservoir Wall and Poured Patches

cement guns, pneumatic tools and air hoists. Heavy demolition was undertaken with standard paving breakers, but the bulk of the chipping and cutting was done with six chipping tools of a design recently developed in Canada.

An electric mixer specially fitted for the dry gunite mix fed two cement guns through screens and gravity hop-
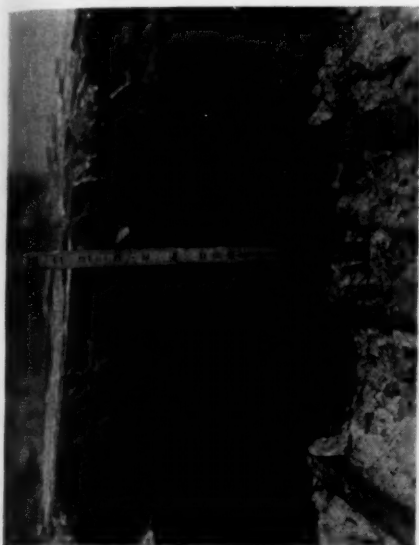

Fig. 3. Close-up of Reservoir Wall Deterioration

pers. Each gun was equipped with modern Dual Hydration nozzles which were used to shoot all the gunite, including the dome roof and the massive ring section. Safeway scaffolds, drills, power saws, air hoists and other miscellaneous equipment also played their part. Finally the wire-winding machine, more commonly called the "merry-go-round," completed the picture. This machine, which makes these large dome roofs possible, will be described in detail later.

Demolition and Chipping

The first part of the job was the removal of the old roof. This was accomplished by the use of heavy paving breakers. To save unnecessary handling and to eliminate the necessity of hoisting, jumbos mounted on wheels were erected inside the reservoir. A heavy wooden platform was built on the top of each jumbo at an elevation just sufficient to clear the underside of the beams. The breaking was then done over the top of these platforms; the rubble was shoveled into buggies, wheeled across the roof and dumped
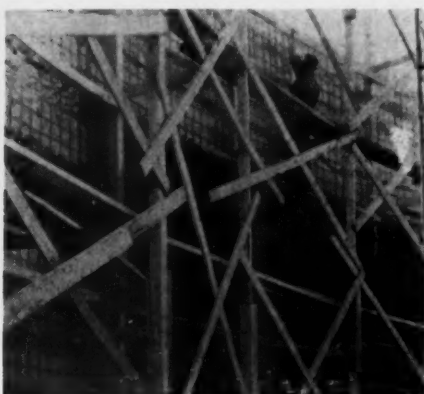
Fig. 4. Single Coat of Gunite Over Reinforcing Mesh of Interior Wall

down a chute into trucks for disposal.

The columns were not removed. As they only displaced 12,000 gal., it was considered uneconomical and unnecessary to remove them. The caps were cut off and the tops grouted over.

Chipping of the interior wall began as soon as it was considered safe under the roof demolition. Movable scaffolds were used in the early stages, but wood scaffolds built in place were gradually erected around the walls, as these served not only for chipping and

gunite application, but formed part of the supporting structure for the dome forms at a later stage.

The entire wall surface was roughened and chipped with pneumatic tools, and all cracks and construction joints were cut out to a depth sufficient to insure a proper seal and bond. The wall was then thoroughly cleaned and all loose surface material removed by waterblasting and sandblasting. The

were broken through to the outside at several locations.

Repair of Walls

After chipping and cleaning, gunite anchors were set in the concrete, with their centers approximately 30 in. apart, and the entire area was covered with electrically welded No. 6 steel wire mesh (6 × 6 in.) secured to the anchors.

Fig. 5. Exterior Wall During Chipping and Repair of Reinforcing

concrete was found to be in fairly good condition except for the one band mentioned, about 15 ft. above the floor.

This 4-ft. high area extending completely around the walls was eroded to a considerable depth, exposing the main reinforcing. The concrete was soft and porous, and chipping operations were carried out with care, as it was considered unsafe to cut into the wall to a point beyond the middle. Despite all precautions, however, holes

Immediately before placing each coat of gunite, the surfaces to be treated were thoroughly waterblasted. Then the gunite was shot on in two or more successive layers to build up the required thickness (Fig. 4). On the interior walls, a minimum thickness of 1½ in. was required, but, because of the heavy chipping, the average was much higher. The final coat of gunite was screeded with straight edges to secure an even surface and then fin-

ished with wood floats. At the joint between the wall and floor, a key was cut and subsequently filled with gunite built out to a substantial cove, although there was no evidence to show that any leakage occurred at this point.

The outside wall was very porous. It was found that the outer shell of concrete was not bonded to the inner portions (Fig. 3) and fell away quite readily. In places the chipping operations exposed the new gunite on the inside. The reinforcing was badly displaced and had to be reset and wired in place, after which it was thoroughly sandblasted (Fig. 5). During this operation some unusual objects were taken from the old wall: about two dozen horseshoes, six dozen pick heads and several rubber boots.

The outside wall was finally sandblasted and waterblasted. A heavy base coat of gunite was shot to fill the deep holes and bond the old steel. This was allowed to cure. In the meantime the walls had been excavated to the footing. The concrete below grade was found in excellent condition and only the construction joints were cut out. Gunite hooks were then placed over the entire wall, reinforcing No. 4 mesh (4 × 4 in.) was secured to the anchors, and the gunite was shot in two coats. The final coat was screeded and finished with wood floats.

The floor, after being cleaned, was found to be in excellent condition, and no repairs were required. A sump was installed, however, and a drain provided under the wall to the outside street sewer.

The gatehouse was gunited inside and out in the same manner as the reservoir proper. Because the existing floor and walls were too low to accommodate the increased water level, it was found necessary to raise the up-

per part and build a new floor, the water level within the gatehouse being equal to that in the reservoir. This work was completed without raising the roof elevation, as sufficient head room already existed. The exterior was remodeled somewhat, glass block windows installed, and a steel platform and ladder replaced the old concrete walkway and stair.

Construction of Dome Roof

The prestressed dome roof on the Halifax Reservoir, with a diameter of 164 ft. 3 in., is the largest of its kind in the world. The shell is $2\frac{1}{2}$ in. thick and has a radius of 171 ft. Obviously, such a shell, from its own dead weight plus any live load which may be imposed, develops tensile stress in the ring, as well as meridianal shear and bending stresses in the shell itself.

In the construction of the dome roof, the stresses are carried by prestressing the main ring, which is built around the perimeter of the shell, and by the use of standard steel reinforcement. The prestressing is designed to induce sufficient compressive stresses to reverse the tensile stresses set up in the ring and shell under the maximum load condition. The bending and shear stresses, which are greatest near the ring, are compensated for by means of standard steel reinforcing and by thickening the shell itself. The seating or connection of the new dome roof to the old structure was the first consideration requiring particular attention. It was necessary to develop a positive connection between the new ring and the old structure. It was also known that some movement would take place in the ring as the compressive forces of prestressing were built up. At the same time, the joint had to be watertight from the inside under the hydro-

static pressure which would be developed.

The top of the old wall was cut down to the required elevation and leveled off. A key was cut down in this surface to form the joint illustrated in Fig. 6. The inside half of the joint was prevented from bonding with the ring by a ¼-in. mastic joint. This joint was subsequently covered on the inside

in sections and set in place by instrument. A full form was used on the outside but on the inside the form was built up to the springing line of the dome only.

The dome forms were carried on a series of posts from the floor of the reservoir, with their centers 10 ft. apart and set in concentric rings. Crosspieces were fastened across the
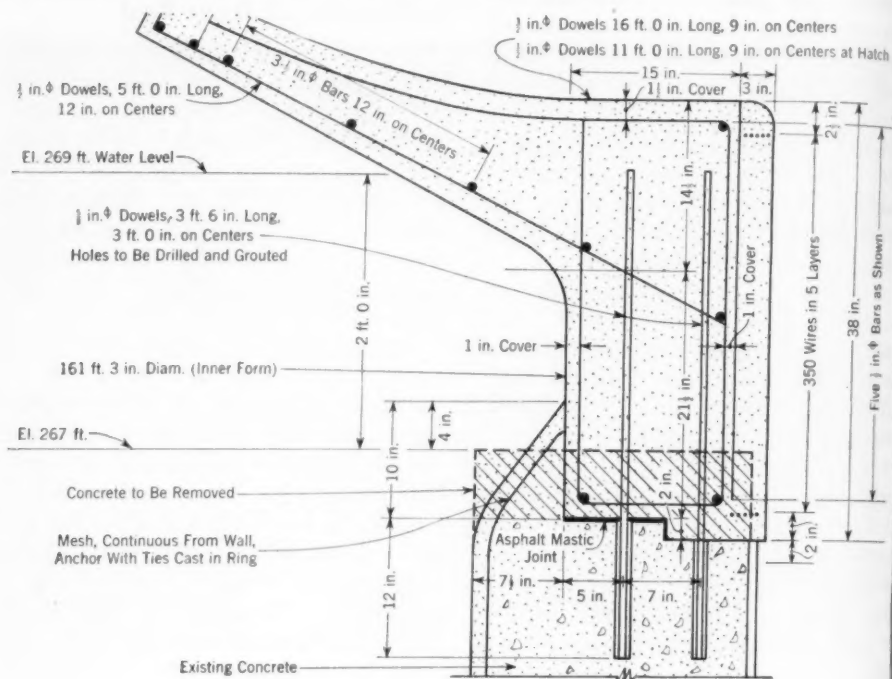
Fig. 6. Connection of Dome Roof to Wall

by overlapping the gunite lining and bonding it to the ring itself. This final operation was, of course, performed after prestressing.

The first step in the construction of the roof was to erect a tower in the middle of the reservoir to set the center point. Since the old walls were not truly circular, an average was taken to establish this working point. The ring forms were prefabricated on the ground

tops of the posts at predetermined elevations to suit the contour of the dome. Radial ribs were then laid up on these crosspieces, each rib cut to template with the correct curvature. The ribs were set with wedges to permit adjustment for final setting. The ribs were then sheeted over with light form lumber and a series of contours run by instrument to check and adjust for curvature (Fig. 7).

The main reinforcing in the shell itself was an electrically welded No. 6 steel wire mesh (6×6 in.) weighing approximately 42 lb. per 100 sq.ft. The mesh was supported on the form by small chairs to locate it in the middle of the shell. Special reinforcing was used around the manway and ventilator to transmit the stresses at these openings.

Gunite was used throughout in the construction of the roof because it is particularly well suited to prestressed construction, producing considerably higher strengths—an essential feature of the design—than ordinary concrete and being more economical for the light sections involved. Also, the loss of stress in the steel due to plastic flow and shrinkage is less in gunite than in concrete construction.

The ring, containing about 90 cu.yd. of gunite, was shot first and allowed to set for several days before shooting the shell itself. This procedure to some extent prevented shrinkage stresses from being transmitted to the shell. The dome was then shot in a continuous operation. Two cement guns were used in 2 12-hour shifts, for five and a half days, to complete the shooting (Fig. 8). As the shell was built, cement finishers followed the nozzlemen with special screeds and wood-floated the gunite to a smooth and even surface.

Curing was a most important consideration, as it affects the quality of the work to a marked degree. The procedure followed involved placing a perforated circular pipe around the ventilator curb and allowing water to flow over the dome continuously. This was supplemented by revolving sprinklers. During the actual shooting operation, the gunite was simply kept wet with hoses and sprinklers. The dome was cured for two weeks before the prestressing operations commenced.

Prestressing Reservoir Rim

In the prestressing operation, a special high tensile strength wire, especially developed for this class of work, was used. The wire is about 0.162 in. in diameter before being drawn and has a yield point in excess of 180,000 psi. and an ultimate strength in excess of 220,000 psi. The wire is applied with an initial stress of about 140,000 psi. This high stress is necessary to allow for loss of stress which occurs from shrinkage and plastic flow in the gunite and from creep in the steel itself. A great deal of research has been done on this subject, and many complicated theories have been advanced to account for the magnitude of this loss. In the Halifax design, a working stress of 110,000 psi. was used, allowing for a total loss of 30,000 psi. from all causes. This is believed to be a conservative figure and is borne out by experience in the field and tests in the laboratory.

Five layers of wire were applied in continuous spirals on the ring, using a total of about 42 miles, or 12,000 lb. of wire. Each layer was bonded immediately after winding with a thin coat of gunite, and, when this was set, the next layer was applied. The final layer was covered with about an inch of gunite for permanent protection. Two layers of wire were also wound on the remaining part of the old ring to induce some measure of prestress in this part of the structure and to assist in the transmission of stresses from the new work to the old.

The wire-winding machine (Fig. 9) hangs from a supporting carriage which travels on pneumatic tires around the ring. Tie cables to a center pin ex-
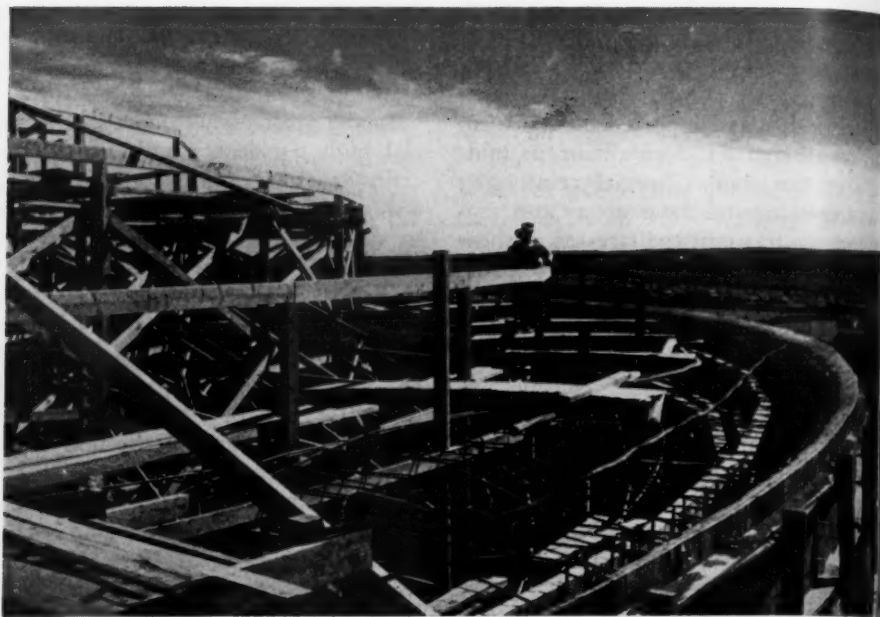
Fig. 7.   Forms for Dome Roof

Fig. 8.   Application of Gunite to Reservoir Dome

tending through the center of the dome hold the carriage to its track. The machine itself is self-propelled; a drum operated by a gasoline engine engages an endless wire rope passing around the perimeter of the structure being prestressed. A spring-loaded take-up is provided to maintain the amount of tension required for proper traction. Vertical travel of the mechanism is

a few hours to apply the mileage of wire needed for an ordinary tank or roof.

Comparing the old roof with the new dome, it was found that, including the columns, the old roof contained 590 cu.yd. of concrete and 60,000 lb. of steel. The new roof, including the ring, contains only 300 cu.yd. of gunite and 27,000 lb. of steel.

FIG. 9.　Prestressing Rim of Reservoir With Wire Winding Machine

obtained by hand wheels operating a simple winch device, although on newer machines this is done by automatic power drive. The wire, which is carried on a reel mounted on the working platform, is led to a die of predetermined size, through which it is drawn to develop the necessary stress in the wire. Winding of the wire starts at the bottom of the ring from an anchor set in the gunite and proceeds spirally around the circumference. Each coil of wire is jointed to the following roll by a special torpedo splice. The machine travels at a speed of about 3 mph., requiring only

Inspection Tests and Results

Strict field control was maintained on this project, with sieve analysis and colorimetric tests being taken regularly as the job progressed. Density and porosity tests were made from time to time by a qualified chemist of the National Research Council of Canada. All test results were excellent.

Difficulty was encountered first in making a true comparative sample of the gunite in the structure for compression tests. Finally the method described below was used successfully, and results showed strengths of well over 4,000 psi.:

A 6-ft. board (12 × 2 in.) placed horizontally was shot with the mixture being used to a thickness of 4 in. or more. After the mortar had taken a firm initial set, usually about one hour, it was trimmed inward from the edges of the board to a distance of approximately 1 in., to permit the placement of 4-in. screed boards. These boards were set in place and used as guides for cutting the mortar surfaces by sharp-edged tools, to a depth parallel to and 4 in. from the bottom of the slab. A 4 × 6-in. high wooden or steel cylinder was used to mark out specimens approximately 8 in. apart (center-to-center) along the center line of the top surfaces of the slab. The material was then cut away, outside of the circular marking, by sharp-edged tools (such as trowels) until specimens slightly more than 4 in. in diameter were obtained. The steel cylinder was set on top of the specimen and was used as a vertical guide, for a cutting spade having a sharp lower edge, a width equal to $\frac{1}{2}$ the circumference of the cylinder, and a shape curved to fit the surface of the cylinder. This tool is approximately 8 in. long and is equipped with a suitable handle. It is operated vertically to shave the specimen to true dimensions, using the cylinder as a guide. Upon completion, the specimens were immediately covered with burlap and kept thoroughly moistened for a period of 12 hours, after which they could be moved and immersed in water or otherwise cured.

The entire outside surface was finished with a white cement weatherproof brush coat. Fill has been placed against the outside wall to a height of 15 ft. above the original grade. Next year this will be graded and seeded and the adjacent property made into a scenic park, with benches and flower beds improving a once desolate "Hungry Hill."

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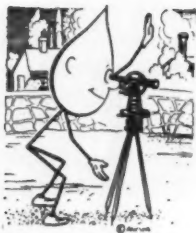
Care of Power Tools and Equipment

By D. M. Van Norman

POWER tools and equipment are vital to the creation and smooth functioning of any water system. Such equipment as air compressors, pumps and motor vehicles of all sorts, powered by gasoline, diesel oil or electricity, are used for a variety of purposes. It is important that they be maintained in working order and that advance provision be made for their replacement, when necessary.

In the Los Angeles Dept. of Water and Power, the great variation in physical conditions under which power equipment must perform makes its proper care and maintenance a matter of considerable importance. The Los Angeles Aqueduct System is more than 350 miles long and extends from the Owens Valley in the Sierra Mountains across the Mojave Desert through the Tehachapi Mountains to San Pedro Harbor. Thus it can easily be understood that all kinds of climatic conditions, from the freezing temperatures of the mountains to the dry. excessive heat of the desert—as well as the fogs and salt air of the coast—are encountered in the course of normal operation. Likewise. equipment operating conditions are influenced by air densities ranging from those experienced at sea level to those at thousands of feet of elevation, and by road conditions varying from the modern paved

highway to mere trails across the desert and mountainous terrain.

At present, the Los Angeles Water System operates 522 cars and trucks of various sizes, ranging from 10-ton capacity trucks towing 10-ton trailers down to $\frac{1}{2}$-ton pickup trucks, passenger cars and a few jeeps. The average distance traveled per year by this fleet under wartime conditions (from 1942 to 1945) was 4,229,075 miles.

These trucks and cars operate in the Los Angeles Metropolitan Area under all kinds of conditions, some delivering pipe to new subdivision tracts, others hauling freight over desert and mountain roads to numerous points along the aqueduct.

To keep the equipment running with as little loss of time as possible, particularly during the past wartime years, has been a tremendous problem. Due to the inability to obtain new equipment, it has been necessary to operate cars and trucks far beyond the mileage limits set prior to the war. For example, cars and pick-up trucks that had once been turned in for replacement after registering 60,000 miles are now being operated at 120,000 miles and more. Inability to obtain new units has made operation of this older equipment necessary, and naturally has increased the amount of maintenance and repairs necessary. The present

method used by the Los Angeles Water System in the maintenance of its transportation equipment may be outlined briefly.

Methods of Upkeep

Automobile inspectors are assigned a certain group of cars and trucks, which they inspect monthly. This inspection consists of a thorough examination of the car or truck, including a check of the engine, transmission, brakes and other parts. A record of each inspection, which indicates the miles traveled, future repairs needed and any other pertinent data, is made. If an inspection indicates that a unit is in immediate need of repair work, an inspector's shop order is written for the repairs needed and given to the transportation dispatcher, who orders the unit into the shop as soon as he can furnish a replacement for it.

The inspector's shop order is then turned over to the shop foreman, who estimates the cost of labor and material required to repair the unit. If this estimate is less than $50 for cars or $100 for trucks, it is assigned to the various auto machinists in the shop, and the work is begun. If the estimated repairs exceed the above amounts, however, the shop order is transmitted to the transportation office, where the cost of the upkeep of the car or truck is checked. When the records indicate that the cost of repairs are warranted, the inspector's shop order is approved: the job card number is assigned; and the order is returned to the shop foreman, who immediately starts the repairs.

If the work is a general overhaul, the motor is sent to the motor shop. Repairs to the transmission or differential are handled by an auto machinist working in the pits. The electrical

shop takes care of generators, starter and all wiring. After the job is completed, the unit is turned over to the tune-up men who analyze the burned gases to evaluate the combustion efficiency. The equipment is then turned over to the inspector to whom it is regularly assigned. He checks it thoroughly and, if it is satisfactory, turns it over to the dispatcher to be put into operation. If it is not satisfactory, it is returned to the shop for further work.

Heavy construction equipment is handled by a different crew of men listed as heavy construction machinists. These men repair caterpillars, cement mixers, trenchers, compressors and similar equipment. The system controlling performance of the work is much the same as that for mobile equipment, except that more repairs are done in the field by heavy construction machinists and, when possible, ordinary repairs are performed on the job on which the equipment is being used.

Rental Charges

Every piece of equipment working for the department is covered by a daily equipment card. The number of hours the equipment is worked is marked on the card, and a rental rate is charged against the job on which the equipment is working. These figures, reported by the man in charge, are checked against the gasoline consumption at the end of the month and, if there is a discrepancy, it is assumed that the equipment cards are not being kept properly. This fact is called to the attention of the superintendent in charge of the division in which the discrepancy has occurred; a retroactive check is made; and the cards are corrected.

Servicing Equipment

Lubrication is the oiling or greasing of moving parts and the changing of lubricant of engines, transmissions and differentials. Several methods are used to determine when lubrication is required.

Mileage Basis

The oil in cars and trucks up to but not including 1½-ton trucks is changed every 2,000 miles if the unit is equipped with an adequate filter. If the filter is not considered of sufficient capacity, the oil is changed whenever it appears to contain an excess amount of contamination—carbon, fuel dilution, metal cuttings or sludge.

The oil in 1½-ton or heavier trucks is changed every 1,000 miles, and the vehicle is lubricated at the same time. Transmission and differential lubricants in cars and light trucks are changed every 10,000 miles; in trucks of over 1½-ton capacity, changes are made every 5,000 miles.

Gasoline Consumption and Time Basis

The frequency of oil change for stationary equipment, such as air compressors, blowers, pumps and generating units, depends upon the quantity of gasoline used. For example, a 105-cu.ft. compressor is lubricated and has an oil change after using 150 gal. of gas, or 48 hours of steady running. The engine oil is changed in heavy movable equipment, such as tractors, motor graders and trenching machines, after every 48 hours of operation, but the equipment is lubricated after only 8 hours of operation. The lubricant in the transmission and differential is changed after approximately 1,000 hours of operation.

The lubricant generally used comes in the S.A.E. 140 range, except for special cases, in which the manufacturer's recommendation is followed. Oil filters are installed on all except very small types of equipment. Filter elements are changed when the oil or dip stick shows excessive contamination.

Exception is made to the customary practice when an analysis of the used oil from any unit shows excessive oil contamination before the limit set. For such equipment, a change is made compatible to the type of operation to which the equipment is subjected. For example, intermittent operation and too frequent use of the choke cause quicker oil contamination.

To maintain all this equipment, it is necessary to have service trucks working in the field. These trucks are equipped with an air compressor, force-feed lubrication grease guns, gasoline tanks and so on. These mobile service stations lubricate and service equipment on the job.

Air Cleaners

Air cleaners, either of the dry or oil bath type, are cleaned at every lubrication period. If conditions warrant, they are cleaned every time the equipment is serviced.

Tires and Tubes

Tire maintenance consists of checking air pressure weekly on all pneumatic tire equipment. At this time the tires are also checked for cuts, breaks, abnormal wear, proper mating on duals and the need for tire rotation.

In mating tires on duals, the diameter differential must not exceed ½ in. This check shows whether the wheels are not aligned and, if any abnormal condition is found, the equipment is immediately sent to the shop for correction.

Any tire on which the tread is worn almost smooth, although the carcass is in good condition, is removed for recapping. Tires that have once been recapped are regrooved when the tread has worn smooth, to prevent skidding. They are not recapped more than once, however, under normal circumstances. It was found that the shortage existing during the war made it necessary to recap tires as long as they were in fair condition, but under present supply conditions, and with increased road speeds permitted, it is considered unsafe to carry an old carcass too long.

TABLE 1

Increase in Maintenance Costs, 1942–45

	Increase per cent
Gasoline	5.71
Motor oil	7.34
Batteries	39.32
Tires	27.43
Maintenance labor	31.76
Materials	95.61
Miscellaneous	5.40
Unallocated expenses	14.38
TOTAL AVERAGE INCREASE	24.00

Increase of Maintenance Costs

Some facts pertinent to the operations of the automotive fleet during a three-year period from July 1, 1942, to June 30, 1945, may be listed:

Maintenance and operation costs increased 24 per cent, as itemized in Table 1; mileage decreased 6 per cent. The factors causing this difference are, in order of importance:

1. Decrease in mileage, caused by gasoline rationing and curtailment of system extensions.

2. Decrease in maintenance activities. Often there was a shortage of materials because of government requisitioning for military installations of pipe and fittings from the department's stock on hand. Frequently it was necessary to fabricate or repair parts in the department shops that in normal times could have been replaced much less expensively. Often transmission gears, shafts and other unobtainable parts were made and installed in the shops.

3. Inability to replace units of the fleet with new equipment, thus necessitating continued repairs to units that would otherwise have been replaced.

4. Increased cost of labor.

5. Increased cost of materials and parts for repairs. As time went on, these were almost impossible to obtain for the older car and truck models.

6. Another factor that is hard to estimate was caused by the induction of experienced operators into the military service. This forced the department to use whatever available men could be adapted and trained.

All of these factors, of course, made the operation of the fleet unusually costly.

Treatment by Operators

The amount and kind of maintenance work needed depend to a great extent upon the treatment which equipment received from the operators. Everyone knows what "gunning" the motor and "jackrabbit" starts do to a car and truck. There is no need to detail abuses of racing motors, quick application of the brakes and other common abuses of careless drivers.

One important detail that should be stressed is the difficulty in convincing drivers of the importance of care in starting a cold engine. The engine, when last stopped, was hot. The hot oil was thin and thus drained from the cylinder walls into the crankcase. Cold starting therefore means a few

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seconds of metal rubbing on metal. Excessive choking floods the cylinder walls with raw gasoline, which washes off the small amount of oil remaining. Often the resulting damage is aggravated because the driver then races the motor to warm it up. If the driver would let the motor idle for at least five seconds after starting with normal choking, the reduced wear on cylinders and piston rings would add at least one-third to the life of the engine.

Maintenance Crew Required

Six inspectors in shop and field check equipment in and out for repairs. They write reports of work to be done, maintain records of equipment and make minor repairs.

Forty-six garage attendants service the equipment. They lubricate, make oil changes, check water in radiators and batteries and examine tires. In addition, they steam-clean, wash and polish equipment.

Thirty-one auto machinists repair the equipment. There are specialists for motor repairs, brake repairs, engine tune-ups, electrical needs, wheel aligning and chassis repairs. These men are listed as motor men, brakemen, tune-up men, electricians, wheel men, pit men and helpers. Outside shops and field have fourteen additional auto machinists.

There are nine heavy equipment machinists of all types to maintain the equipment in the heavy class. Outside shops and field have two more heavy equipment men.

Besides the specialists mentioned, there are two each of the following: battery men, metal men, upholsterers and painters.

Two dispatchers route the equipment to its correct destinations.

Conclusion

It may be seen that many variables influence the life of power tools and equipment. Smooth functioning of such equipment requires the full cooperation of all: the inspector, the shop mechanic and the equipment operator.

Mutual Aid Program for Peacetime

By Earl Devendorf

THE success of the New York State Mutual Aid Program, which was developed during the early days of the recent war and became a national pattern for the country, has been widely discussed and reviewed (1–5). The program was designed to assist local water supply and sanitation authorities in meeting emergencies and to facilitate the prompt rendering of aid from adjoining or neighboring communities. It was developed as a part of the mobilization of the state and its communities to safeguard or restore water service promptly and effectively in wartime emergencies or peacetime catastrophies.

Under the provisions of Chapter 574 of the Laws of 1942 passed by the New York State Legislature and approved by the Governor, the needed authority for carrying out the objectives of the Mutual Aid Program was provided. The original act was the result of a study of the State Dept. of Health in co-operation with the Conference of Mayors, the Town Association and a committee of the Legislature. Subsequently, under the provisions of Chapter 729 of the Laws of 1946, constituting Section 120-u of the General Municipal Law, the Mutual Aid Plan was placed on a permanent peacetime basis. The text of this chapter is given in the appendix to this paper. Certain provisions that related

solely to the war have been eliminated in the revised statute, but the essential features of the program that have proved to be of value and use in peacetime operations have been retained.

Under the provisions of this statute, the state is divided into 22 zones which are identical with the existing State Dept. of Health districts, except for the separate zones comprising Westchester, Nassau and Suffolk counties.

A key water works official was appointed as a zone co-ordinator in each zone, and the district engineers of the State Dept. of Health and the county sanitary engineers of Westchester, Nassau and Suffolk counties were appointed as assistant zone co-ordinators. With the proposed reorganization plans of the department, it is contemplated that some of the existing health districts will be consolidated or abolished, with the result that it may be found desirable to make some modification of the present zone areas in the future.

A sanitation and water works manual was compiled and published by the New York State War Council for the purpose of providing constructive information and guidance for local water authorities. This manual, which is a valuable reference book, was placed in the hands of all water works authorities in the state. Additional copies are still available for distribution, and

every water works superintendent and foreman is advised to obtain a copy if he does not already have one.

There is no longer a need for the continuation of the special water service training schools through which 2,500 volunteer and regular water supply personnel received instructions in accordance with the lessons outlined in the manual. With the end of the war, the State Dept. of Health, in co-operation with the Municipal Training Institute, is again conducting training courses for water works operators, the first having been held April 14–16, 1947. These schools will satisfactorily meet the need for training of water works employees.

During the early months of the war, one of the most important features of the program was the mutual aid inventory of water works material. This inventory, which was necessitated by the ever-increasing difficulty of obtaining critical water works materials, was undertaken in co-operation with a specially appointed Inventory Committee of the New York Section of the A.W. W.A. and was planned with the co-operation of the War Production Board and the Office of Civilian Defense. With the close of the war, the need for maintaining such an inventory no longer exists.

Through the operation of the Mutual Aid Program, many municipalities whose maps and records of the water supply distribution system had been lost or mislaid were supplied with such records. One of the important earlier objectives of the program was the promotion, to the greatest degree possible, of inter-connections wherever feasible and practical between adjoining public water supply systems, so that, if the water supply in one system should fail, service could be continued

in some measure by drawing upon the other. The records and replies received from the zone co-ordinators show that throughout the state there are now 228 such inter-connections. Since the connections are only practicable where the water systems are in close proximity, it follows that the majority have been installed in densely populated areas of the state. There have been numerous instances where the use of these inter-connections has proved of value in preventing interruption in water service, where such relief measures would otherwise have been impossible.

A brief, general summary of the accomplishments of the Mutual Aid Program is all that has been presented here. Although some of the procedures that were adopted, such as the inventory of water works equipment and the training of water works auxiliaries, have been discontinued because of changed conditions at the conclusion of the war, much of the original program will continue to be of value to water works authorities.

Experience has shown that the program has resulted in a closer bond between water works superintendents and officials than ever existed before, and that it has brought about a realization that all municipalities have a common interest in the all-important problem of maintenance and operation of our municipal water supplies.

As previously stated, the success of the New York State Mutual Aid Program has been due largely to the loyal and conscientious efforts of the zone and assistant zone co-ordinators, the water works authorities and the support of the A.W.W.A. The continued co-operation of all these agencies in peacetime is essential, if the program is to continue to function effectively in

emergencies, facilitating aid from adjoining communities and insuring the prompt restoration of water service.

References

1. DAPPERT, ANSELMO F. New York State Mutual Aid Plan for Water Service in Case of Emergencies. Jour. A.W.W.A., **34**:189 (1942).

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3. ———. Mutual Aid in New York During 1942. Jour. A.W.W.A., **35**:201 (1943).

4. ———. Recruiting and Training Auxiliaries for Water Works. Jour. A.W.W.A., **35**:1090 (1943).

5. ———. New York State Mutual Aid Program. Jour. A.W.W.A., **37**:73 (1945).

APPENDIX

Chapter 729 of the Laws of New York of 1946

An act to amend the general municipal law, in relation to mutual aid for water service in municipalities in the event of emergency. Became a law April 14, 1946, with the approval of the Governor. Passed, three-fifths being present.

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

SEC. 1. Subdivisions one and two of section one hundred twenty-u of chapter twenty-nine of the laws of nineteen hundred nine, entitled "An act relating to municipal corporations, constituting chapter twenty-four of the consolidated laws," such section having been added by chapter five hundred seventy-four of the laws of nineteen hundred forty-two and thus renumbered by chapter seventy-five of the laws of nineteen hundred forty-three, are hereby amended to read as follows:

1. As used in this section: (a) "Municipal corporations," "municipality" or "municipal" means and includes any city or incorporated village, which owns and operates a water system for domestic, commercial or public uses; and subject to the provisions of subdivision thirteen, a water district located within a town;

(b) "Water system" means and includes all the pipes, pumping stations, elevated tanks and other structures and appurtenances necessary to the delivery of water under pressure and owned and operated by a municipality, water works corporation, industrial corporation or other water purveyor;

(c) "Inter-connection" means and includes all of the piping, valves, pumps or other appurtenances installed between two different water systems which are necessary to make it possible for water from either system to be supplied to the other.

(d) "State co-ordinator" means the state co-ordinator of water supply appointed by the state commissioner of health pursuant to the provisions of this section.

(e) "Emergency" means a temporary condition of failure or inadequacy of the supply of water resulting from stress of weather, convulsion of nature, fire, failure of power, mechanical breakdown, breakage or stoppage of mains and other portions of the water works system either from accident, malice, acts of war or civil commotion, or other generally unforeseeable events and temporary interruptions of service due to repairs, replacements or extensions.

2. It is hereby found, determined and declared to be in the public interest that a mutual aid plan for water service in

event of possible emergency be established for municipalities, water works corporations and other purveyors of water in this state; that an adequate and continued supply of water to all the people of the state is a public purpose vital to the public health and welfare; and that any municipality in the exercise of its powers hereunder will be performing an essential governmental function vital to the public security and for the protection of the property of the municipality and its inhabitants.

SEC. 2. Paragraph (b) of subdivision three of section one hundred twenty-u of such chapter, such section having been added by chapter five hundred seventy-four of the laws of nineteen hundred forty-two, and thus renumbered by chapter seventy-five of the laws of nineteen hundred forty-three, is hereby amended to read as follows:

(b) to construct necessary waterlines to extend water service and to acquire necessary lands, easements or other interests in lands and rights of way therefor either within or outside of the municipality for that purpose;

SEC. 3. Subdivision four of section one hundred twenty-u of such chapter, such section having been added by chapter five hundred seventy-four of the laws of nineteen hundred forty-two, and thus renumbered by chapter seventy-five of the laws of nineteen hundred forty-three, is hereby amended to read as follows:

4. Inter-connections or extensions located wholly or in part outside the bounds of the municipality shall be constructed in accordance with the provisions of law, ordinance or regulation applicable to the construction of municipal public works located within the constructing municipality. The making of such inter-connections and the continued supply of water through any such inter-connection located wholly or in part outside of the bounds of the municipality for a period not longer than the necessary and unavoidable duration of the emergency and in no case for a period longer

than six months shall not require the previous consent and approval of the water power and control commission. However, extension of water service outside the bounds of a municipality shall require the prior consent and approval of the water power and control commission. The municipalities or water works corporations or other purveyors of water which shall have their water systems inter-connected for emergency purposes shall have joint control, possession and supervision over such inter-connections under the terms of a joint agreement to be effected by them and shall have all the rights, privileges and jurisdiction necessary or proper for carrying such powers into execution. No provision of this section shall operate to limit or restrict any municipal power otherwise granted by law.

SEC. 4. Subdivision five of section one hundred twenty-u of such chapter, such section having been added by chapter five hundred seventy-four of the laws of nineteen hundred forty-two and thus renumbered by chapter seventy-five of the laws of nineteen hundred forty-three and such subdivision amended by chapter seven hundred ten of the laws of nineteen hundred forty-three, is hereby amended to read as follows:

5. Whenever a municipal corporation shall have authorized the construction of the whole or part of any inter-connection, or any extension of a line to provide water service, the officers charged by law with the duty shall prepare a map or plan of the improvement, until such map and plan, if it be for an inter-construction of the inter-connection or extension nor shall any rights of way be acquired therefor nor shall any expense be incurred by any municipality, except for the preparation of the map or plan of the improvement. No contract shall be entered into for the connection, shall be presented to and approved by the state co-ordinator, nor until such map and plan if it be for an extension shall be presented to and approved by the water

power and control commission with such modifications, if any, as he or it, as the case may be, shall determine. Upon approval of plans for an inter-connection, the state co-ordinator shall file a certificate thereof with the clerk or corresponding officer of the municipality proposing the improvement and in the case of a town water district, with the town clerk of the town in which such district is located. Whenever a municipal corporation shall propose to construct an inter-connection jointly with another municipal corporation, or jointly with a water works corporation or other purveyor of water, the proposals shall provide the portion of the expense to be borne by each and shall be submitted to the state co-ordinator for approval. The submission of proposals by a municipal corporation for the construction of an inter-connection jointly with another municipal corporation, water works corporation or other purveyor of water, shall not bind the municipality to the performance of the work or of any part thereof, and any such municipal corporation may withdraw from the proposal at any time prior to the execution of the contract for the performance of the work. The municipal corporation shall have power to acquire by purchase or eminent domain proceedings, lands and easement rights necessary for the improvement both within and outside of the municipality. This section, however, shall not authorize the taking of any lands already devoted to a public use. In any proceeding for the acquisition of lands or easement rights or other interests in land where the municipality is unable to acquire the same by purchase, the municipality after written notice served upon the parties to whom such lands are assessed on the last annual tax rolls either by leaving the same at the residences of the parties or by publication in the official paper or papers and after filing with the supreme court a map and descriptions of the land to be taken, shall have the power to enter immediately upon such lands and to proceed with con-

struction of the inter-connection or extension, but the compensation to be paid to the owner of such lands shall be ascertained as soon as practicable by the supreme court without a jury and in such event jurisdiction is hereby conferred upon the supreme court to do every act which commissioners of appraisal may do under the condemnation law. Nothing herein, however, shall operate to restrict the powers of a municipal corporation to acquire lands or easement rights for a public purpose in a manner otherwise provided by law. It shall be lawful for any municipal officer or employee charged by law with the duty to acquire lands and easement rights for the municipality to enter upon private property without the consent of the owner for the purpose of making inspection, investigation, examination or survey or for any other purpose relating to the construction of an inter-connection or extension or the acquisition of lands and easement rights therefor.

SEC. 5. Subdivision twelve of section one hundred twenty-u of such chapter, such section having been added by chapter five hundred seventy-four of the laws of nineteen hundred forty-two and thus renumbered by chapter seventy-five of the laws of nineteen hundred forty-three, is hereby amended to read as follows:

12. To further the purposes of this section, to promote the installation of needed inter-connections and the reinforcement of water supply systems to meet any possible emergency conditions and to facilitate the interchange of water works personnel, equipment, materials or supplies between municipalities, water works corporations or other purveyors of water in event of emergencies, the state commissioner of health may appoint a state co-ordinator of water supply and may divide the state into any number of water service zones and appoint zone co-ordinators of water supply and assistant zone co-ordinators of water supply who shall be officials or employees of the state department of health, municipal or county departments of health or public

works or municipal water works and shall serve without additional compensation for services rendered under or pursuant to the provisions of this section. It shall be the duty of all local water officials to co-operate with the state and zone water supply co-ordinators on all matters related to mutual aid for water service.

The state co-ordinator shall have power:

(a) to investigate and study existing water systems in the state as to the need for their reinforcement, integration or inter-connection to meet the requirements of any public emergency;

(b) to collect and disseminate information and data and to engage in technical studies, scientific investigations and statistical research relating to inter-connecting water systems;

(c) to collect and disseminate information and data on the extent and availability of water personnel, water equipment and other water works materials and supplies;

(d) to ask for and receive aid and assistance from zone co-ordinators, assistant zone co-ordinators and municipal and water works officials in the performance of his duties;

(e) to review and co-ordinate plans and preparations for exchange of personnel, equipment, materials and supplies between municipalities or between municipalities and water works corporations and water districts in an emergency;

(f) to review and approve or disapprove plans for the inter-connection of water systems.

Each zone co-ordinator, with the assistance of the assistant zone co-ordinator, shall have jurisdiction within the water service zone in and for which he is appointed:

(a) to aid in the preparation of plans for water inter-connections or extensions;

(b) to tabulate the extent and availability of personnel, equipment and other water works materials and supplies;

(c) to formulate plans for the expeditious use of the available personnel, equipment and other water works materials and supplies in case of an emergency.

SEC. 6. Paragraph (a) of subdivision thirteen of section one hundred twenty-u of such chapter, such section having been added by chapter five hundred seventy-four of the laws of nineteen hundred forty-two and thus renumbered by chapter seventy-five of the laws of nineteen hundred forty-three, is hereby amended to read as follows:

(a) Notwithstanding the provisions of section one hundred ninety-seven of the town law prohibiting the award of contracts if the total expense of the improvement shall exceed the maximum amount proposed to be expended for the improvement as stated in the petition for the establishment or extension of the district, the town board may direct the town engineer, or if there be no town engineer, a competent civil engineer duly licensed by the state of New York, to prepare a map and general plan for the construction of an inter-connection between the water system of the district and any other water system or for the construction of an extension of the water system of the district and to prepare an estimate of the portion of the expense thereof to be borne by the district. When such map, plan and estimate are submitted, the town board shall call a public hearing thereon and cause a notice thereof to be published and posted and such hearing to be held, all in the manner provided in section two hundred and two-b of the town law. After such hearing and from the evidence given thereat, if the town board shall determine that it is in the public interest to construct the inter-connection or extension and that all property and property owners within the district will be benefited thereby, it may proceed with the work subject to other applicable provisions of this section. A copy of the determination of the town board, signed and

certified, shall be duly recorded in the office of the clerk of the county in which the town is located and when so recorded shall be presumptive evidence of the regularity of the proceedings of the town board. Any interested party aggrieved by the determination of the town board may review the same in the manner set forth in article seventy-eight of the civil practice act provided that application for such review is made within thirty days from the time of filing the determination in the office of the county clerk.

Sec. 7. This act shall take effect immediately.

Proposed Amendments to A.W.W.A. Constitution

The following amendments to the Constitution of the American Water Works Association have been properly proposed to and are recommended by the A.W.W.A. Board of Directors. In accordance with Article V, Sec. 1.6, of the Constitution, the proposals will be submitted for discussion at the annual conference to be held in San Francisco, July 21–25, 1947. In studying these recommended changes, members should refer to the present text of the Constitution as printed on pages 207–211 of the November 1946 Membership Directory.

The recommended revisions are as follows:

Art. III, Sec. 2-f—*Amend to read:* The latest living Past President of the Association who is, *ex officio,* Chairman of the General Policy Committee.

Art. III, Sec. 2-h—*Amend to read:* The Chairman of the Committee on Water Works Administration.

Art. III, Sec. 2—*Add subsection* i *to read:* The Chairman of the Publication Committee.

Art. IV, Sec. 1.3—*Amend the first sentence to read:* When more than one name is nominated for *any* office, the election shall be by letter ballot.

Art. V, Sec. 1.1—*Amend to read:* Proposals to amend this Constitution may be made by any ten or more Active Members of the Association, provided that such proposals are filed, in writing, with the Secretary not less than 30 days prior to any stated meeting of the Board. It shall be the Secretary's duty to submit such proposals to the Board of Directors at its next stated meeting.

Art. V, Sec. 1.2—*Amend to read:* The Board shall consider the proposals at any stated meeting (Constitution Art. III, Sec. 9; Art. IV, Sec. 1) and the proposers shall be notified of the Board's action in regard thereto *not later than 30 days after such meeting.*

Art. V, Sec. 1.3—*Amend to read:* The proposers may then withdraw their proposals, accept any change suggested, or insist on the original form, sending their decision to the Secretary *not later than thirty days after the date of the Secretary's notice of the Board's action.*

Legislative Protection for Indiana Ground Waters

Presented herewith is the text of Chapter 154 of the Indiana Acts of 1947 recently enacted by the State Legislature and signed by the Governor on March 12. This first legislative step for the control of water in Indiana was taken on the initiative of the Indiana Department of Conservation, which caused the bill to be introduced in the State Assembly early this year.

A BILL for an Act to conserve and protect the ground water resources of Indiana, and to require a permit for the use of such waters for air-conditioning and cooling purposes.

WHEREAS, during the past several years the use of ground water for municipal, industrial and air-conditioning purposes has increased tremendously and,

WHEREAS, ground water levels in many cities and industrial areas have receded to a point where the adequacy of the supply is being threatened, and

WHEREAS, the sewerage systems of many of these areas are being overtaxed as a result of excess quantities of ground water used for air-conditioning and cooling purposes being discharged into them.

WHEREAS, the public health and welfare may be jeopardized if the use of ground water for air-conditioning and cooling purposes is left unabated, therefore:

Be it enacted by the General Assembly of the State of Indiana:

SEC. 1. That it shall be unlawful after *January 1st, 1948,* for anyone to remove more than two hundred gallons per minute of water from the ground by any means and use it for air-conditioning or cooling of air purposes un-less said waters are circulated through cooling towers or other devices and re-used, or are returned to the ground through recharge wells or a permit is secured as provided for in Section 3 of this Act. A recharge well may be dug, driven, drilled, or any other type of well or pit which has a capacity of returning water to the ground by gravity in excess of the amount removed from the ground to supply the air-conditioning or cooling unit. More than one well or pit may be used as a recharge well in the event one well cannot be obtained which will take an amount of water in excess of the amount being removed from the ground, but the total receiving capacity of such wells or pits must exceed the volume of water removed from the ground which is used for air-conditioning or cooling of air purposes.

SEC. 2. No water used for air-conditioning or cooling of air purposes shall be returned to the ground through recharge wells which has been exposed to the atmosphere or which in any way has been contaminated or will not meet the requirements of the State Board of Health for a water which is safe from a public health standpoint to return to the ground. Before any water from an air-conditioning or cooling of air

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system is returned to the ground a permit must be secured from the State Board of Health.

SEC. 3. Water may be withdrawn from the ground and used for air-conditioning and cooling of air purposes in excess of the quantities specified in Section 1 of this act, if a written permit is first obtained from the Indiana Department of Conservation. The Department will issue such permits free of charge and shall deny permits only in such cases as their studies of the ground water resources of the area affected are sufficiently conclusive to indicate that the removal of additional ground water for air-conditioning and cooling of air purposes will affect the ground water resources of the area to such an extent that it will be injurious to the public health and welfare of the community.

Errata—*Standard Methods*—Ninth Edition

The following corrections to the text of the Ninth Edition of *Standard Methods for the Examination of Water and Sewage* (1946) have been reported:

1. Page 24, Sec. 10, B, 1.6 (Standard calcium chloride solution). In the formula, *for:* "Mg. CaCO₃ per ml. potassium palmitate = [0.5 × ml. standard calcium soln.] ÷ ml. potassium palmitate," *read:* "Mg. CaCO₃ per ml. potassium palmitate = [ml. standard calcium soln.] ÷ ml. potassium palmitate soln."

2. Page 54, Sec. 24, D, 3 (*Preparation of Iron Standards*). In line 6, *for:* ". . . to about 40 ml., add 0.5 ml. of 3N HCl . . . ," *read:* ". . . to about 40 ml., add 5 ml. of 3N HCl . . . ."

3. Page 216, Appendix 1, Sec. 4, col. 1, line 31. *For:* "Copper does not interfere below 0.2 ppm., the maximum limit permissible according to the 'Drinking Water Standards of the U.S. Treasury Dept.,' " *read:* "Copper does not interfere below 0.2 ppm."

These are the only corrections to the Ninth Edition that have been called to the attention of the editorial staff. Any other errors discovered should be transmitted to:

Reginald M. Atwater, M.D.
Executive Secretary
American Public Health Assn.
1790 Broadway
New York 19, N.Y.

Water Quality Litigation

Holder v. Windsor Utilities Com.

A resume of an action before the Supreme Court of Ontario, Windsor, Ont., Can., on Dec. 16, 1946, prepared and first published by "Waterworks Information Exchange," official publication of the Canadian Section, A.W.W.A.

ALLEGED harmful chemicals in a public water supply were the subject of recent litigation before the Supreme Court of Ontario (*William E. Holder* v. *Windsor Utilities Commission*). A resume of the action is presented herewith.

Evidence of Plaintiff

The plaintiff claimed that he was suing on behalf of himself and all other water users for damages resulting from the action of the commission in treating the water supply by adding harmful chemicals. No stated damages were asked.

Mr. Holder stated he was a "medical electrologist" and a "doctor of naturopathy"; he had studied medicine for two years somewhere in England; he had dabbled in chemistry; and he was then in his 79th year. He had spent many years in research on the causes of ill health and had written two books: one on "Why Humanity Suffers," the other dealing with cancer. He had originated the use of high frequency electric current treatment, and he had, in the last three years, after many years of research, completed equipment which he called a "metallic indicator." This apparatus measures the metallic units in water, milk, food and the human body (when electrodes are placed on the tongue). He stated that the Ontario Dept. of Health had calibrated this equipment in 1943.

He stated that the instrument measures the metallics in the human body, and that these are the forerunners of cancer, tuberculosis, poliomyelitis, heart trouble, hepatitis, arthritis, ulcers and other disorders. Any measurement of metallic units in excess of about 20 indicated these diseases, and all kinds of symptoms were produced. Cancer cases at Winnipeg, Man., had been found to record 27 units. He was unable to describe what a unit was.

He stated that this metallic indicator is a reliable instrument for testing water; that it measures the "metallics" present; that when 30 to 35 units are present the water is bad; and that a reading of 38 units registers sulfate of alumina.

He stated that he had been in good health when he came to Windsor six years ago, but that he had contracted hepatitis and other illnesses there. On inquiry, he found that the city was using aluminum sulfate and ammonium sulfate in its water supplies. He complained to the Water Commission, to the government at Ottawa and to the Provincial Dept. of Health at Toronto, but no action had been taken. When he discontinued use of the Windsor

water and used distilled water, he became well again.

Cross-Examination of Plaintiff

In cross-examination, the plaintiff revealed that the metallic indicator was not patented—"it was too intricate for that"—and stated that over 18 metallic units in a water is dangerous. The Windsor supply measured about 32. On further questioning, he admitted that his metallic indicator was an ammeter which measured the current that overcame the resistance of the substance being tested. He could not say that the Dept. of Health or any doctor had endorsed this instrument. He admitted that a larger quantity of these chemicals in the water did not make it more dangerous, since the effect was cumulative, but claimed that a higher dosage would act more rapidly on the consumer.

He stated he had tested 1,500 waters, and had found 2 places where the water was safe. Every water over 20 (previously given as 18) was unsafe. London water had 32 units. Windsor had 25 to 37, and Toronto was quite bad at 33 units. The Ontario Dept. of Health was approving water supplies which were unsafe.

The condition of these waters was due to harmful chemicals. These were sulfate of aluminum and sulfate of ammonia, with sulfuric acid. He did not object to the use of chlorine, nor did he mention bacteriology. His objection to the water was that these chemicals were being introduced in the treatment and were reaching the consumer. He stated that 65,000 cases of illness had gone through his hands. He made his living from the manufacture of these machines, and from the publication of books and sale of "anti-met" tablets.

The plaintiff called a further witness who stated he contracted arthritis after drinking Windsor water, but when he followed Mr. Holder's advice and drank distilled water he recovered (he was badly crippled as he went to the witness stand).

This concluded the case for the plaintiff.

Evidence of Defendant

The defendant Utilities Commission called two witnesses: A. E. Berry of the Ontario Dept. of Health and J. C. Keith, Manager of the Windsor Utilities Commission.

Evidence of A. E. Berry

Mr. Berry gave evidence about recognized practice in water filtration and attested that the Windsor plant was modern and efficient in action. The plans for the plant had been approved by the department, and its operation had been inspected regularly.

He stated that the alum used did not pass the filters, but reacted with the water to form other compounds. There was therefore no aluminum sulfate in the filtered water. Furthermore, sulfates were not injurious, and they were common in water supplies. The recognized limit for general suitability of water for domestic purposes has been given as 250 ppm., whereas Windsor water had only about 25 ppm.

The witness stated that the "metallic indicator" developed by Mr. Holder had been examined, and an attempt made to calibrate it in relation to the strength of the solution. It was found that the readings did not bear such a relationship, and the machine was not calibrated by the department. It was found to be somewhat similar to a Dionic conductivity tester, used by the department about 30 years ago and

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abandoned as being of negligible value. The metallic indicator measured the resistance to current of a solution. It makes no distinction between the different minerals in water and could not be considered useful in water testing.

Evidence of J. C. Keith

J. C. Keith, Manager of the Windsor Utilities Commission, gave evidence that the filtration plant had been built and operated with the approval and under the supervision of the Ontario Dept. of Health. No complaint had been made against their procedure by the department, and the results of the treatment had been very satisfactory. This concluded the e v i d e n c e. Neither solicitor offered any argument before the decision was given.

Decision of Justice

In giving his decision, Mr. Justice Barlow stated that the case was a most extraordinary one. The only complaint by Mr. Holder was that sulfate of aluminum and sulfate of ammonia, added in the treatment, were present in the tap water. He accepted the evidence of Dr. Berry that this was not so, and that the operation of the plant and the quality of the water compared very favorably with others. He stated that the plaintiff had presented no evidence of damage. He found, from the evidence, that the water was of first class quality, effectively supervised and properly inspected by the Provincial Dept. of Health. He therefore dismissed the action with costs to the plaintiff.

Industrial Use of Streams

By L. L. Hedgepeth

A paper presented on Nov. 19, 1946, at the North Carolina Section Meeting, Raleigh, N.C., by L. L. Hedgepeth, Pennsylvania Salt Manufacturing Co.; now Executive Secretary, Virginia Water Control Board, Richmond, Va.

THE continued movement of industry southward and the increased sewered population are adding to the waste load of southern streams. This situation has created a demand for effective control of pollution in order to avoid further degradation of the waterways. Water purification plants are the principal victims of stream pollution, and water works men recognize the uncomfortably small margin of reserve assimilation capacity existing in many streams. Some pollution loads can be tolerated by a stream without impairing its health, but other pollution loads will upset its digestion. Failure to appreciate this important distinction results in the misunderstanding which is an underlying cause of indifference and a source of much undesirable prohibitory regulation.

The problem has been recognized in several states which have enacted appropriate co-operative legislation. Other states, including North Carolina, are now undertaking similar legislation.

During 1946, Virginia enacted a water control law to provide for the control, prevention and abatement of pollution in the waters of the state. Beginning Dec. 1, 1946, the author will undertake to administer this law for the State Water Control Board.

Having worked for industry since 1929, the author realizes that the co-operation of industry must be obtained if the program is to be successful. It should be sold to industry's engineers on the merits of each case. Although the objectives of the pollution abatement program are the same from all angles of examination, the approach to its solution is influenced by the employment environment of the individual. Consideration should be given to several fears, certain questions and possible means of solving this problem.

Keeping Payrolls

An industrial friend recently expressed the opinion that the waste water discharge restrictions now being adopted would substantially arrest the movement of industry southward.

In effect he said: "If the new Virginia law prohibits all new pollution how is new industry to be established? Further, existing industries have an exceedingly difficult period ahead if the law requires them to clean up their wastes. These plants must have plenty of water and a place to put it after it is spent in process. Many industrial waste liquor disposal problems are unsettled. Aside from certain labor and climatic advantages, the water supply and waste disposal facilities offered by

presently clean streams are the South's principal industrial inducements."

Except for one defect, this logic is unassailable. If it is clearly understood during design that, although stream abuse will not be permitted, reasonable use will be encouraged, it is believed that industrial technology is sufficiently resourceful to find an economical answer. If there is no answer for disposal of wastes from a specific plant, and stream pollution is going to be an inescapable price of another industrial payroll for the community, then the problem becomes greatly simplified. It may and should be presented to the community on the watershed as a whole: "Are you willing to have this river become an offensive water course as a part of the price of industrial development of this basin?"

The industrial engineer would welcome such a frank approach *before*, rather than have to face it *after,* the plant is built. He is no different in his method of reasoning from any person who makes his living by technical applications. He prefers to arrange his problem in an orderly manner and then to devise a logical solution. Government owes these men a rational delineation of stream pollution abatement requirements to be considered as a part of the problem for plant location.

Industrial Responsibility

A corollary to this fear that stream pollution control will drive away industrial payrolls is the pronounced impression that industry is callous in acceptance of its share of the responsibility. Abel Wolman strongly indicted municipalities and industry in his paper on "Responsibility for Industrial and Municipal Wastes" (1). He was particularly severe on industry. View-

ing the problem in perspective for the entire country, he fixed the pollution load as the discharge of raw sewage from 47,000,000 people and industrial wastes equivalent to an additional population of 55,000,000 to 60,000,000. He classed industry's conception of its rights to pollute streams as a "sacred cow," adding that the general characteristic of industrial stream pollution abatement was, at its best, carelessness; and, at its worst, a complete disregard of industrial responsibility.

Wolman's summation was characteristically apt and should be required reading for management, but the author believes that his indictment of industry is faulty in spots. Particularly objectionable were the allegations of little research on waste disposal, of no studies beyond the sewer outlet and of a disregard of responsibility.

Industry is doing much research in stream pollution abatement, but it appears in the record principally as process improvements—process changes to eliminate waste. That, incidentally, is the profitable point at which to attack stream pollution. Regardless of how they are described, any adjustments which reduce the pollutional load are properly classified as abatement measures.

The author knows a number of industrial plants where stream pollution abatement studies are very comprehensive. Some companies go further and operate mobile laboratories to measure the effects of aerial pollution on the surrounding countryside. Others have stream pollution committees at work, composed of representatives from various divisions of the company. These actions are taken in self-defense, in order to promote good relations. It is good business to keep one's house in order and to be on good terms with

one's neighbors. There is an interesting untold story in this for industry's public relations men.

Finally, the charge of failure to accept responsibility needs clarification. Industry should not be asked to be altruistic. It is silly and wishful thinking to expect it. A corporation is merely a paper creature; it has no conscience; it has no soul. Of necessity it is operated on hard-headed business principles. "I am my brother's keeper" is a valid business principle only to the extent of living up to a reasonable code of standards. Payrolls must be met, books must be kept in black ink, and reserves must be maintained if it is to remain in business.

These healthy signs are not possible if management permits its cost to exceed those of its competitors. Business may exist only by being self-supporting. It has no power to levy taxes for its deficits. Its costs must be kept below its income. If the public wants its streams to be clean, then appropriate legislation, enforced impartially, will be required to be fair to each industrial plant and to place it on an equal basis with its competitors. It is not helpful to the stream pollution abatement movement to indict industry in the absence of such requirements.

Towards a Solution

Much is made of industry's inability to solve all of its waste disposal problems. It is a fact that no generally applicable solution has been found for many such wastes. For example, the sulfite pulp waste liquor problem remains unsolved as a whole, even though several satisfactory individual solutions have been devised. But one does not make progress by becoming appalled over limitations. A good engineer gets

into his work and solves the apparently hopeless problems by paying attention to details. He may not always find the complete answer, but his method is productive of much progress.

The author does not believe that continued abuse of streams should be accepted merely because many phases of industrial waste disposal are unsolved. It has been his good fortune to have a wide acquaintance among the technical men of industry. Most of them would welcome the requirement to complete their work on manufacturing processes so as to eliminate the wastes substantially or arrange for their disposal. They are only human and, being so, have selfish pride in their work. No good man likes to turn out a half-finished job. Well-considered law and regulations should do much to encourage completion of manufacturing processes, thus eliminating a major source of wastes which otherwise would reach the streams.

Poor Control Measures

Conceding that a sound legal structure for co-operative approach is strongly indicated, industry can, without regrets, dispense with those strength sappers—prohibitory regulation and paternalism. Prohibitions result in fines and irritation, and paternalism is wasteful beyond all defense. The author cannot subscribe to the thesis that, if local action does not provide the desired relief, it is the duty of government to step in and play Santa Claus. There are strong, sound objections to being taxed in one section so that government can solve competitors' problems in another. If work needs to be done on waste disposal, it can be accomplished best at the local level by the men in each plant, not by walking delegates of government.

Attacking at the Source

Industrial waste disposal reaches its most effective development through the combined efforts of the chemical engineer on the manufacturing processes and the sanitary engineer on the effluent. As has been observed earlier, the most profitable place to start correction is in the manufacturing process. It is difficult to wax enthusiastic over the outlook for construction of imposing waste disposal structures on the tail ends of industrial sewers. Industry does not think that way. Its problem is quite different from municipal sewage in one important respect, and that is the lack of assurance that any particular waste will be a problem for the length of time required to justify a major investment in a waste disposal plant. Human beings may be expected to continue to eat and eliminate body wastes without much change for a long time. Industry, on the other hand, is continually changing its operations.

When the plant man has done all that is economical on waste reduction in the manufacturing process, the sanitary engineer must then devise a suitable treatment or diversion of the waste liquors so as to avoid stream abuse. But impressive plants should not be expected—the industrial engineer will endeavor to reduce his problem to its simplest form and then arrange for functional waste disposal units.

Specific Examples

The correctness of this reasoning may be illustrated by considering the relatively simple waste disposal problems presented by the manufacture of two synthetic insecticides—DDT and the important but as yet lesser known hexachlorocyclohexane, also called benzene hexachloride, 666 or Gammexane.

DDT is formed in very strong sulfuric acid which merely furnishes the environment for the condensation of the DDT isomers. It does not enter into the reaction. After much use, the strong acid becomes fouled with process refuse and must be withdrawn and replaced with a clean charge. Also, the DDT crystals removed from this syrupy acid must be washed free of acid before being further processed for use.

Thus are produced, for each ton of DDT made, about 700 lb. of foul 93 per cent sulfuric acid and 7,000 lb. of relatively clean 7 per cent acid wash water. The disposal of this acid is the significant phase of the stream pollution problem presented by the manufacture of DDT.

Neutralizing 93 per cent sulfuric acid is no easy task, and diluting it merely complicates the problem by increasing the volume of final effluent. Further, even if it were diluted and neutralized, the organic muck content precludes its discharge into a healthy stream. Obviously a use should be found for this strong waste, or it should be reburned to destroy the organics and to recover its acid values. Therefore, returning to the original thesis of not upsetting digestion by gulping down the stream pollution problem as a whole, but of attacking it forkful by forkful, the disposal of this strong fraction should be considered as a manufacturing problem. This is because its discharge to waste is an economic loss. Viewed in this manner, it is not a stream pollution problem.

It is likely to become one, however, if there are no restrictions on waste discharge into streams and a cost-

conscious management prefers that the time of its engineers be utilized for more pressing problems. Whether we like it or not, the answer to the classic question: "When will a rich man spend a dollar?" remains: "When he can make two dollars." And the author personally has no hope for a change in that attitude, regardless of the type of industry, its geographical location or the political philosophy of the business man.

The 7,000 lb. of relatively clean 7 per cent sulfuric acid wash water produced per ton of DDT is clearly of stream pollution significance—law or no law. This is because of economics.

It is not sensible to attempt recovery of acid values from such low concentrations. Neutralizing with lime and disposal of the clear neutral supernatant in the stream is strongly indicated.

The wastes from hexachlorocyclohexane present an entirely different problem. Available information has it that three tons of presently unusable chlorinated organics are produced for each ton of usable product. Obviously, such a waste of material classifies this process as incomplete. Research simply has not finished its job. Uses should be found for these rejects in order that they may be sold or used as co-products or by-products. If this is not done, the consumer pays an increased cost for the waste, and, in the absence of stream pollution control, the stream will receive much of the rejects simply because that procedure is the cheapest method of disposal.

Sensible Control

Regulation of waste disposal should be accomplished by control measures which are practical. This approach will yield constructive solutions. The average engineer in industry is willing to co-operate and may be expected to find an acceptable answer to waste disposal, if he can present the problem to his management on a "must" basis and if he is permitted a reasonable use of the assimilation resources of the stream. Without his co-operation, little progress on waste disposal will be accomplished.

The action most disliked by industry, and to which resistance all along the line may be expected, is the prohibitory type of regulation. It does no lasting good to have the sheriff wave legal papers at a plant superintendent and drag company officials into court for a fine, except in flagrant cases. Of course, publicity of a sort is obtained. The man on the street will say "The state's finally getting after those fellows—we can start catching fish again before long." But such action merely deludes the public and should be beneath the dignity of a public health engineer. Stream pollution history clearly shows that prohibitory control does not correct stream abuse. Fines paid into courts do not neutralize one pound of acid or satisfy one part per million of B.O.D. Process change and waste disposal construction are the only steps which will reduce the industrial waste load. At one plant in Virginia, the person responsible for solving the waste problem told the author that it would be more economical for his employers to pay a fine of $100 a day for the life of the plant than to make the required sewer separation and build and operate the disposal plant they are constructing.

Pollution Defined

The case for the co-operative approach required decision on when waste discharge is or is not abuse of

the stream. Definition is not easy; it is like trying to define "poison." The only really good definition of poison which the author ever heard comes from Warren Watson, who has been wrestling with it for many years. He says (2) that a poison is "too much." Too much of anything. A half pound of salt taken in one dose may destroy a human life; it is reported to be a form of suicide in China. Yet no one would think of classifying salt as a poison—it is a food.

Investigators have tried for many years to define what constitutes a poison for human beings. Such phrases as: "22 mg. per kg. of body weight," "60 grains for an adult," "easily anticipated doses" and others have been suggested or used. The author served on a committee which studied the problem for several years, but found no toxicologist who would give a definite figure. The committee finally devised a paragraph of definition which satisfies the lawyers and some, but not all, of its medical members. In essence, it says simply: "A poison is too much."

And a similar definition is offered as the nearest approach stream sanitarians should make to a definition of pollution. Pollution to the extent of stream abuse is "too much"—too much load for the stream to assimilate and remain healthy. And it covers everything discharged into a stream. Not just too much B.O.D., sludge, grease, acid or alkali, but too much of anything.

Pollution could even be caused by too much chlorine, that servant of public health men, who consider it a useful treatment for sewage and waste effluents, and use it freely. Sanitary engineers do not normally think of chlorine as a pollutional substance. But it must be classed as such, if "too much" is discharged into a fishing stream. Too much chlorine can kill algae in catastrophic numbers, thus upsetting the production cycles of fish food. The discharge of a heavily chlorinated effluent into a recreational stream should be carefully evaluated by fish life authorities before being authorized.

Similarly ammonia, an algal food, commonly considered by sanitarians as a harmless substance in effluents, must be regarded with suspicion in a fishing stream. It is highly toxic to some game fish.

According to the author's limited viewpoint, the best determination of what constitutes pollution is accomplished by pooling thought in each case and settling details at the local levels. The method may not always provide a perfect answer, but it does get the load reduced, and, by this means, progress is made. One grows a little weary of discussions about setting standards of purity for each stream. Engineers are accustomed to the use of yardsticks in their work and usually prefer to have standards established for each stream. But when deciding on how to bell the cat in this field of technical work, standards do not mean much. Local conditions must take precedence.

Waste Disposal Objectives

What can be set as a goal? General objectives would be to remove the sludge, scum and grease, destroy or divert objectionable concentrations of toxic agents, reduce discoloration to imperceptibility in the stream, adjust the effluent pH to the normal stream range, and reduce the flowing load B.O.D. to the point where it can be assimilated by the stream without dropping the dissolved oxygen below acceptable minimums. Even these gen-

eralizations are too inflexible for some specific applications.

The author has endeavored to present this problem as requiring firm co-operative regulation based on sound law. Legislative action is needed to provide a skeleton of strong girders on which appropriate regulation can be constructed to stay, weathering the storms which will certainly come. Once this structure is provided, the corrective actions become largely technical, not legal. Sanitary and chemical engineering of the most exacting type will be needed. Stream pollution law and enforcement regulations cannot exceed the proved art and science of waste disposal. If such are attempted, the law will be set aside by the courts, repealed by the next legislature, or unenforced simply because it cannot be enforced.

If the problem is approached on the premise that the true measure of the wealth of a community is the production of goods, and that the public need requires both that our plants operate and that stream degradation cease, industry's engineers will co-operate to find a workable answer.

The men who comprise industry resent the idea that they must be fought on matters of public need. They like to think of themselves as being good citizens and good neighbors—and must do so, or they would lose their self-respect. They are a part of the public that must drink the water from these streams. They like to fish and swim in them, and when they do, they don't like to wade through sludge, or see waste and sewage particles float by. They can be sold on Phelps' beautiful concept (3) of considering a stream as being a living complex thing of loveliness, of health, of enjoyment—a valuable resource capable of serving man in a multitude of ways and too often rendered unfit for any but the most menial of services through pollution and defilement.

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Survey of Unaccounted-for Water in Minnesota

Minnesota Section Committee Report

A report of the Minnesota Section Research, Survey and Advisory Committee presented on Mar. 13, 1947, at the Minnesota Section Meeting, St. Paul, Minn., by O. E. Brownell, Public Health Engr., State Dept. of Health, Div. of Sanitation, Minneapolis, Minn., Chairman.

UNACCOUNTED–FOR water has been defined as the difference between the quantity of water obtained from the source and the quantity actually delivered to the customers. The amount of water "unaccounted for" does not necessarily indicate the efficiency of plant operation, for a system may have a very large water waste which can be accounted for, thus presenting a low unaccounted-for figure. On the other hand, a high unaccounted-for figure may reflect loss of both water and revenues, as well as operational inefficiency.

Every water utility should determine carefully the proportion of its supply which is unaccounted for, to make sure that its operation is on a sound footing.

Perhaps "lost" or "non-revenue" water would describe the problem more accurately. As water used by city departments is usually non-revenue water, however, the term "unutilized" water is suggested instead. The restriction of extravagant water consumption by city departments, incidentally, will help increase the efficiency of a municipal water department. It is very satisfying to be able to account for all the water that has been pumped or paid for, and the process of accounting for it may disclose

losses through leakage, waste or theft which can be remedied if the savings justify the effort.

For the purposes of such an investigation, water must be considered indestructible. A negligible quantity does evaporate from open tanks and basins, but in general an attempt must be made to account for the entire amount pumped from the source.

The Research, Survey and Advisory Committee on Unaccounted-for Water of the Association's Minnesota Section collected data on the subject from 31 water departments in Minnesota. The data covered a period of a year, during which 38.994 bil.gal. of water were supplied to 1,074,183 people by these departments—an average per capita consumption of 100 gpd.

A considerable variety of data was reported to the committee, some of it unusable. Three departments accounted for more water than they drew from the source. Several reports were outstanding in the completeness of their lists of uses of water and in their general results obtained. The results are summarized in Table 1.

When analyzing the problem, it is apparent that inaccuracy and inconsistency in the measurements and estimates of the quantities cause a large part of the difficulty. It is possible to

overestimate the quantity taken from the source, thus introducing an amount that is necessarily unaccountable. In an incomplete survey or listing of the many uses of water, some are overlooked and therefore become unaccounted for. The essentials of an attack on the problem are: (1) complete honesty in using the data, (2) a complete list of the uses of water and (3) accuracy in measuring and estimating quantities.

TABLE 1

Summary of Data on Unaccounted-for Water

Water Use	Amount	
	mil.gal.	per cent
TOTAL from source	38,994	100.0
Consumers	29,983	77.0
Fire service	68	0.3
City uses	2,228	6.0
Leakage	717	1.7
Theft	negligible	
Unaccounted for	5,894	15.0

The following list of municipal uses of water has been assembled from the data sheets and files of the committee:

Filling lakes, park ponds and pools, fishponds, and swimming and wading pools; flooding skating rinks; watering lawns and trees in parks; flushing and sprinkling streets; flushing sewers; operating flush tanks on sewers; flushing dead-end mains; flushing snow to remove it; sprays for children; public buildings; bleeding to prevent freezing; cleaning reservoirs and basins; draining and cleaning elevated tanks; overpumping reservoirs and tanks; construction purposes (obtained from hydrants); building construction; water plants; meter testing; wash water for filters; sludge removal; street drinking fountains; street sweepers; employees' dwellings; chlorine apparatus; back-filling trenches; sewage lift stations; watering troughs; cemetery

watering; cooling towers; steam boilers; sewage treatment plants; municipal golf courses; municipal cow pastures; municipal pounds; and toboggan slides.

The accurate measuring and estimating of water present many difficulties. All meters with moving parts tend to under-register with age, and it is desirable to have accurate meters or to make allowances for their inaccuracies. A meter will not over-register unless its gears are altered. Meters at the source can be calibrated by pumping to receiving reservoirs and elevated tanks and through weir boxes. Master meters, venturi meters and orifice plates can also be employed. An estimate based on the rate of pump discharge and the duration of pumping is better than no estimate at all.

A recording voltmeter or an electric clock can be used to record intervals of pump operation. This total time multiplied by the rate of pump discharge equals the daily pumpage. This method was used by one department.

It is generally conceded that customers' meters under-register. Of 28 departments reporting, 14 made corrections, varying from 2 to 5 per cent, for under-registration. It would appear that for each water supply a corrective factor could be arrived at, based upon examination of the meters under operating conditions. For water used by other departments in the city, the co-operation of the department officials is necessary.

It is noted that for 60 per cent of the people served by municipal water supplies, the unaccounted-for water amounts to nearly 6 bil.gal., which, at an average rate of 10¢ per 1,000 gal., costs $600,000. This can be considered a fairly accurate representation for the

rest of the state, which means that out of a total of 66 bil.gal. annually pumped from sources for the five hundred water supplies, 10 bil.gal. is unaccounted for. This amount, at 10¢ per 1,000 gal., represents $1,000,000. The serious side of the problem is to determine what portion of this amount of water is leakage that warrants correction. Twenty-three departments reported a total leakage loss of 717 mil.-gal., valued at about $71,700. For the entire state, the leakage has an estimated value of $122,000. On the basis

Fig. 1. Reports on Unaccounted-for Water

of other leakage surveys, this figure is estimated as high as $800,000.

It is likely that the leakage figure is too low. The answer lies in conducting leak surveys, locating and estimating the quantity of leakage, using leak detectors and carrying out programs for eliminating the loss of water which has been paid for. A simple survey can be made by shutting off one section of the distribution system at a time by valves and supplying water to it through a hose or temporary line equipped with a meter to measure the

water. This work is best accomplished between midnight and 5:00 A.M. With lead-jointed pipe, the allowed leakage per mile per inch of pipe diameter in 24 hours is estimated to vary from 100 to 500 gal. The average leakage of several cities has been estimated as about 16 per cent of the total pumpage. It is thought that about 4 per cent would be lost from mains, 8 per cent from services, and 4 per cent from under-registration of meters.

As some of the factors considered and overlooked are of seasonal occurrence, it is obvious that the amount of unaccounted-for water would vary if it were computed for each quarter. That this is true is being demonstrated in a study now being made in this matter. A quarterly breakdown of the data might disclose errors that creep in when the data are considered on a yearly basis.

Figure 1 shows the percentages of unaccounted-for water reported. It appears that the very low and high reports are out of line and could well be dropped out. The average would then drop to 11 per cent. With more care and accurate data, it seems probable that this figure could be further lowered. It does not seem impossible to obtain a figure of 5 per cent.

Dewey W. Johnson (1) reports a leakage survey that resulted in accounting for all except 5½ per cent of the water and the data presented well corroborate the work of the committee.

The results obtained by the committee so far may be summarized as follows:

1. The data obtained are, to a large extent, incomplete and inaccurate.

2. They seem to agree with similar data which have been published.

3. More work should be carried out to obtain more definite and conclusive results. A selected number of places could carry out a well-planned project, the results of which could be used as a pattern by others. Later, new data could be assembled by the entire group and compared with the results obtained by the present study.

Reference

1. JOHNSON, DEWEY W. Losses in Distribution Systems. Jour. A.W.W.A., 39: 157 (1947).

Erratum—A.W.W.A. Specifications 7A.5—1940

Sixth and Seventh Printings

In setting the type for the Sixth and Seventh Printings of "Standard Specifications for Coal-Tar Enamel Protective Coatings for Steel Water Pipe of Sizes 30 Inches and Over—7A.5—1940," an error was made in reproducing the old document. This error has been corrected in preparing the Eighth Printing and does not appear in any printing previous to the Sixth. The correction is given below for users of the Sixth and Seventh Printings:

On page 7, Sec. 2.5.4 (6) *Impact Test,* first line: *for* "The $12 \times 12 \times \frac{7}{16}$-in.," *read* "The $12 \times 12 \times \frac{7}{64}$-in."

Office Procedure in a Small Water Works

By F. G. Gedge

B Y "office procedure" is meant the process of accounting for receipts and disbursements. It is through the collection of bills that overhead costs can be paid and a surplus for extensions and improvements created. At the Wyoming, Ohio, water works, a routine office procedure has been adopted that controls all financial aspects of operation in an orderly and systematic way.

Accounting for Disbursements

Duplicate purchase orders are made out for all items which are not, like power and chemicals, ordered on contract. One copy of such purchase orders is sent to the supplier and the other copy retained to check against the delivery slip and invoice. After the invoice is checked, the delivery slip and duplicate purchase order are thrown away. A voucher is then prepared and the invoice attached to it. The voucher shows the ledger account to which the item is charged. Payrolls are vouchered in the same manner, and labor cost is allocated on the voucher to the various accounts.

After the checks are made out and the check numbers noted on the voucher, the vouchers are recorded in a register (Fig. 1), which is kept in installments, from board meeting to board meeting, with a break and subtotal at the end of the month, so that a running cash balance may be kept on the reverse side and checked against the bank balance on the first of each month. Each page is easily totaled in each column and the page is balanced across its width. These totals are then transferred to the yearly page, on which each month runs across the page and is totaled to insure that the amount posted agrees with the page total.

A comparison sheet, on which the items run down the column instead of across, is also kept. This list is useful for quick reference at board meetings in making available an easy check on items that fluctuate in monthly expenditure. Thus it can be ascertained whether operations are normal and whether any item of expense is running excessively high.

Purely for convenience, a ready-reference monthly page is kept of operating costs. On this page, actual vouchered expenditure figures are used for all but softening plant material costs, which are entered according to the month's actual use of materials as determined from the monthly chemical and analytical report. These analytical reports are kept and filed by years.

At the end of the year, the columns on the yearly page are transferred to

the proper ledger account as single items, rather than by monthly breakdowns. The double entry system is used in keeping the control ledger and journal, which also carry a set of gross value accounts and reserve for depreciation accounts covering the plant, wells, machinery and distribution system. In other words, depreciation of plant and equipment is considered part of the cost of producing water, and

Accounting for Receipts

All services are metered and a record of each is kept on a meter card which lists the name and address of customer, size of meter, account number, tap number and location of meter on the premises. The meters are read by the police in their off-time. When cards are turned in at the office after the reading, consumption is determined and priced on the meter cards.

VOUCHER REGISTER

JAN. VOUCHERS PAID
FEB 19, 19—

| | NUMBERS | | STATION | | SOFT'G PLANT | | LINE | | MAINS | |
	VOUCHER	CHECK	MAT'L	LABOR	MAT'L	LABOR	MAT'L	LABOR	MAT'L	LABOR
MATHIESON ALK.	3398	289			71357					
B&O. R.R	99	90			20503					
PAY ROLL '/9	3400	91 to 300			4336	9324				
PUB. EMP. RT'MT	01	01				200				
F.G. GEDGE	02	02 to 03								
W.F. SPREEN	03	04 to 05		10000		7500		6470		
R. MONTEITH	04	06 to 07		3095		16000				
R. BOEHME	05	08								
PAY ROLL '/16	06	09 to 19			2560	9324				
PETTY CASH	07	20			200					
PAY ROLL '/23	08	21 to 26				9324				
COUNTY TREAS.	09	27								
REM'N RAND	10	28								
CINTI. VULCAN	11	29	1665							
REV. PUB. CO	12	30								
SUB. SPLY CO	13	31			4173					
NEPT. EQU'T	14	32								
EURA SEC'TY CO	15	33								
GARLOCK PK'G.	16	34	570							
WORTH'N P. CO	17	35								

FIG. 1. Portion of Voucher Register

that factor is included in the rate base. Thus, when the plant is worn out, there will be sufficient reserve for replacements without resort to bond issues. No bond retirement is charged as the total bonded debt has been paid back to the sinking fund. The only interest which must be charged to expense is the difference between the interest due on the bonds outstanding and that earned by the sinking fund investments.

Postcard bills, with detachable stubs are used. Both sides of the cards are addressed on an "Elliott" addressing machine before the meters are read and the account number is shown on both bill and stub.

As accounts change or new customers are added, address plates are made in the office to keep the list up to-date. Plates and meter cards are filed and used by streets, rather than alphabetically by customers' names.

The main books of account are the Cash Book, the Consumers Ledger and the Miscellaneous Ledger (the latter two may be combined if desired). These accounts are kept in conformance with the requirements of the State Auditor's office, but the Voucher Register and the General Purpose Ledger and Journal are kept for the information and convenience of the water works itself. By adhering strictly to state requirements, it is possible to determine at the year's end whether or not over-all operations have been profitable, but it is difficult to determine which practices are resulting in profit and which in loss. For example, it is perfectly possible to earn a profit while installing new services at a loss. Thus, if enough new services are installed, the loss may absorb the surplus earned on the production of water.

The water bill stub, which carries the account number, is returned with the check or cash payment. Each day's receipts are sorted alphabetically, totaled on an adding machine and deposited in the bank. The stubs are then alphabetically entered in the cash book, showing the account numbers and the amounts paid. These entries are then totaled to make sure that the total posted agrees with the stub total. If a mistake has been made it is noted in pencil, and the next day's deposit adjusted to correct the error.

Miscellaneous receipts, such as those from the sale of meters, service permits, cleaning services and repairs, are entered in a triplicate receipt book with numbered stubs. One copy is the customer's receipt, the second goes to the maintenance department for execution of the work, and the original stays in the book as a check against the cash book for the State Auditor.

When such sales are made and the cash is deposited in the cash box, a stub is made showing the amount and the miscellaneous account number. These receipts are handled in the same way as are those from sales of water.

The Consumers Ledger is kept in alphabetical order, with names and ac-

WYOMING WATER WORKS

No.	NAME	Delin-quent	QUARTER ENDING MARCH 31, 1946						Delin-quent	QUARTER ENDING JUNE 30, 1946					
			Cu. Feet Used	Amount	Add'l Charges	Discount	Amount Paid	Date		Cu. Feet Used	Amount	Add'l Charges	Discount	Amount Paid	Date
A.1	ABRAMS, FRANK		1300	235			235	4-19		1700	295			295	7-23
A.2	ACH, EUGENE		4400	655			655	4-3		8000	1105			1105	7-6
A.3	ACHOR, MRS. L.		1800	310					310	1700	325			635	7-9
A.4	ACKERSON, MRS. GEO.		8500	1168			1168	4-3		2800	455			455	7-17
A.5	AHERN, JACK.		900	175			175	4-9		2000	340			340	7-17
A.6	AKIN, MRS HARTLEY		4000	605			605	4-3		6700	943			943	7-5
A.7	ALCORN, MRS. H. R.		1100	208	160		368	4-15		DISCONTINUED					
A.8	ALDERKS, O. H.		1100	205			205	4-9		1700	295			295	7-23
A.9	ALEXANDER, R.W.		5400	780			780	4-9		6400	905			905	7-31
A.10	ADDIS, GEORGE T.		800	160			160	4-15		1600	280			280	7-31
			29300	4478	160		4348		310	32800	4743			5258	
				4478			4348				4743				
				160			310				310				
				4638			4658				5253				

Fig. 2. Portion of Consumers Ledger

count numbers on both margins (Fig. 2). Extra pages are cut and inserted so that the pages need not be typed more than once every two years.

The consumption and charge are posted directly from the meter cards, and payments are credited from the cash book. Any penalties or overpayments are shown in appropriate columns, and delinquent accounts are carried over to the next quarter. At the end of each quarter each page is totaled and balanced and a recapitulation made of all pages. This total, together with the miscellaneous sales, is then balanced against the cash.

On the first of September of each year, the delinquent accounts are listed, together with property owners' names. From this list an assessment sheet is made out and filed with county auditor for collection as taxes. After the first of January following, the County Treasurer's books are checked, the paid assessments totaled and the Village Clerk billed for the amount collected. These collections are then handled in the same way as the regular cash receipts.

A petty cash account of $50 is carried in the cash box for making change and for paying small express, freight and other charges. When such items accumulate they are vouchered, and the distribution shown on the voucher. Petty cash is then reimbursed. It is strongly recommended that no checks be cashed from this fund unless one is quite sure they are good.

At the close of business each year, the disbursements and cash receipts are transferred to the control or General Ledger. Inventories are taken, and the books are closed. A trial balance is taken as in any business, and the annual statement prepared for distribution to the members of the board and the council. This statement shows: assets and liabilities, profit and loss account, comparative operating statements for the past three years, pumpage and distribution, cost of water pumped, trial balance, services added and total in use, and all other information pertinent to the operation of the water works.

Such methods permit a continuous check on all phases of operation and enable those in charge to obtain easily, accurate knowledge of the economic functioning of the system.

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Comparative Study of Swedish and American Water Treatment Practices

By Harry L. Schein

A contribution to the Journal by Harry L. Schein, Chief Engr., Merkantila Ingeniörsbyrån Pehr Husberg A.B., Stockholm, Sweden.

WHEN a Swedish engineer makes a study of American water purification practice and attempts to draw comparisons between American and Swedish conditions in this field, a number of factors must be taken into account which have a direct bearing on all the conclusions reached. The different outlooks prevailing in the two countries from both a social and a technical point of view render a direct comparison of these conditions impossible.

Water treatment problems in Sweden are, generally speaking, rather uniform, and deal mainly with the purification of soft surface waters having a high content of organic matter and strong color, without appreciable odor or taste. The American water sources, on the other hand, present a wide range of problems, characterized by stream pollution and all its attendant difficulties. Swedish water, again, is quite satisfactory bacteriologically, but bacterial contamination is a dominant problem in the United States. It should be noted further that, whereas water works in the United States are frequently in the hands of private companies, practically all of those in Sweden are under public control and possess all the advantages and disadvantages such systems entail. Finally, any comparison is influenced by the fact that the greatly superior technical and economic

resources available in the United States permit more intensive research work and a more adequate application of the results of research under practical conditions than may be afforded in Sweden. Energetic initiative in the development of new methods and a marked desire to experiment characterize American water supply engineering, whereas in Sweden a certain conservative tendency may be noted.

Development and Research

To a foreigner paying a short visit, the competitive economy of America appears to be the most vital stimulant to the development of American water supply engineering. It is primarily the large firms, manufacturing and supplying plant and equipment to the water works, which employ their research staffs to find new markets and fields of application, endeavoring to effect improvements in the methods and apparatus hitherto employed, in order to render them more competitive. Furthermore, many large water works carry on direct research work based on their own practical operating experiences, thus making valuable contributions to technical advancement and at times exercising a beneficial restraint upon the pronounced eagerness of certain firms to expand. Finally, research work of a purely scientific na-

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ture is carried on at many American universities with the object of seeking solutions, independently of temporary commercial conditions, to many important questions.

The limited Swedish market does not, as a rule, permit water purification firms or suppliers of mechanical equipment for water works to expand to such an extent that they can maintain their own staff of research workers. Needless to say, opportunities are sought for turning to account the knowledge gained from practical experience and possible mistakes, and efforts are made to apply ideas for improvements to actual service conditions, but these attempts only encompass incidental details, and not organized research activity.

On the whole, the water works in Sweden are quite small, and they are therefore unable to undertake any appreciable development work in this field, apart from the resolving of practical details. Generally speaking, only two or three of the largest water works can afford to carry out experiments on a more extensive scale. Nor is any purely scientific research undertaken by the universities, because the country is too small and its water supply is not considered sufficiently important.

In view of these conditions, it will be readily understood that water purification engineering stands at a much higher level in the United States than in Sweden. As many as ten years often elapse from the time a new method is applied for the first time in the United States before engineers begin to adopt it in Sweden. During the intervening period, they watch developments, study the technical press and endeavor to form opinions regarding the suitability of the method. When the time arrives for its adoption, they seek to adapt it to the more traditional forms, a necessity which sometimes leads to a number of unfortunate compromises.

It must not be thought, however, that Swedish water works produce water which is of inferior quality. On the contrary, the hygienic, and to a great extent the physical-chemical, standards required by law of a public water supply are very exacting. The water supplied to the customers is, as a rule, of a very high quality; quite comparable to, and frequently better than, that supplied in the United States. Primarily this is due to the quality of the raw water, which is usually quite high by American standards. But the fact that the treated water itself fulfills the formal requirements does not, of course, prevent the purification process from being carried out on technically simpler lines and in a more economically suitable manner.

Treatment Methods

Although it is not possible within the scope of a short discussion to present a detailed comparison of the different methods employed, an attempt to show in general terms the different tendencies in American and Swedish water purification practice may be found of some interest.

From a Swedish point of view, coagulation for removal of organic matter and color is of the greatest interest. Because of the uniformity of the Swedish sources of water supply however, these plants have become standardized in principle in the course of time, and, as is well known, all standardization involves a certain risk, where water is concerned. Consulting engineers frequently ignore the fact that careful and repeated coagulation tests should be made with different chemicals. The design of purification plants

also follows more or less routine lines, providing conventional flocculation and sedimentation basins and rapid sand filters. This is very different from the practice followed in the United States, where carefully conducted tests are made often to determine both the coagulant to be used and the design of plant required by the individual circumstances. Moreover, Americans adopt different methods of coagulation on a large scale, such as pre-chlorination, dosing with activated silica and the like. Far greater care is devoted in America to the design of reaction chambers, mixing chambers and sedimentation basins than in Sweden, which unquestionably has much to learn about these matters.

Although surface water constitutes the major part of the total water supply in Sweden, there are extensive districts—which include a number of fairly large towns, particularly in the southern and central provinces—in which ground water serves as the source of supply. There are only three plants in Sweden for softening public water supplies—a number that, notwithstanding the smaller size of the country and the relatively low hardness of its supplies, is all out of proportion to the more than 600 in the United States. Economically, softening plants are one of the most justifiable of public investments, and they can be an important feature of the national economy. Swedish engineers are striving to make their politicians water-minded, and American experience is of the greatest value in the advancement of this work.

America is also in advance of Sweden in the use of smaller softening filters. There is no appreciable difference between the design of American and Swedish filters, it is true, but the use of softened water is far more widespread in certain parts of the United States than in Sweden.

There is, however, a considerable difference from a technical point of view in boiler feed water treatment methods. This may, of course, be due to the fact that the boilers employed in large American industrial concerns frequently work at a higher pressure than is customary in Sweden, and, consequently, are more exacting in their demands for water treatment. Among other methods, the new synthetic resins for demineralization by means of cation and anion exchangers have been accepted in the United States. This system has not yet been adopted in Sweden, although Swedish water, owing to its low salt content, is suitable for treatment by the process.

Swedish progress with the problem of corrosion appears to compare favorably with American work. At a number of places the author even received the impression that insufficient attention is devoted to the question of corrosion. For example, there is no equivalent in the United States to the Swiss MAGNO compound employed in Sweden which has yielded such excellent results, particularly in the removal of carbon dioxide, iron and manganese from the water. Nor does American aeration equipment for the removal of carbon dioxide appear to be comparable with the Swedish INKA-apparatus. It is in just such details—often quite important—that Swedish practice has advanced a long way.

The author has made a special study of water purification for swimming pools, but has not noted any striking differences between American and Swedish methods. In America and Sweden the existing purification plants are constructed on widely differing

lines, but there seems to be entire agreement on matters that would affect the ideal form of purification plant, as, for example, the time of circulation and the form of the filters. Notwithstanding slight differences, the grounds on which the quality of swimming pool water is judged appear to be more or less similar. It is true that the system of separate circulation for chlorine dosage, unknown in America, has been widely adopted in Sweden of late. On the other hand, it is understood that certain experiments with free residual chlorination for swimming pools are in progress in America, and it is possible that the problem of maintaining effective sterilization in all parts of a swimming pool without entailing an offensive chlorine odor may be solved in this way.

In the sterilization of water for human consumption, the United States has a long lead over Sweden. Not only are the methods of application and dosage arrangements for chlorine far superior in the United States, but the application of chlorine not only for sterilization but also for taste and odor control is much further developed. One reason for this greater development is of course the fact that, as the large rivers in the United States serve simultaneously as collecting points for sewage and as sources of supply, water sterilization is of paramount importance. Sweden has a great deal to learn from the Americans about sterilization in general and chlorination in particular.

Because stream pollution is so widespread and affects raw water quality, a very considerable amount of attention has been devoted to the question of sewage disposal in America. In places, the purification of sewage must be carried to extremes in order to obtain a potable water supply at all. This problem does not arise on a large scale in Sweden, despite the increase in population and the constantly progressing industrial development. There can be little doubt that, as Sweden's attention is increasingly directed to sewage treatment, engineers will be obliged to turn to the Americans and profit by their experience.

Social and Economic Differences

It is clearly impossible in a short article to make exhaustive comparisons. The author has attempted only to touch briefly on the important questions in a more or less general manner, and obviously a critical reader could mention special conditions that do not conform to the generalizations made. On the other hand, a long series of further comparisons could be cited, in support of these contentions, to complete the general picture. It is mainly in details of design, suitable planning and—above all—an understanding of the relation between the technical development and its economic importance that the United States is so far in advance of Sweden. This picture would be unjustified, however, if the reverse side were not also examined. There is a close connection between the social standard of a nation and the manner in which it deals with its water problems. Whereas, in Sweden, conditions are very uniform, both from a social and technical point of view, they are widely divergent in the United States. Undoubtedly some regions in the United States are more advanced than others, and consequently there are a large number of communities in which the water supply question has not been settled in an entirely satisfactory manner.

Furthermore, a visitor cannot help observing that certain new methods are

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promoted by means of extensive prop-
aganda although—infrequently, it is
true—they do not possess the technical
merits claimed for them. Similarly,
antiquated and technically unsuitable
methods are often maintained in use
by skillful advertising and the en-
deavor of some companies to solve all
water problems, not so much in an ob-
jective manner as by the application of
processes which happen to be available,
regardless of their suitability to special
circumstances.

Swedish water treatment practice
was dependent to a great extent dur-
ing the 1920's and 1930's upon develop-
ments in Germany, although for many
years past the United States has been
the leading source of new methods for
more efficient water treatment. Not-
withstanding their relatively high tech-
nical level, many of the small European
states, including Sweden, are obliged
to learn from the United States and
avail themselves of its imposing capac-
ity for initiative and its stimulating
wealth of ideas.

Although, generally speaking, ex-
cellent relations have always existed be-
tween engineers in the United States
and Sweden, contacts in the water sup-
ply field have hitherto been few. It is
hoped, however, that closer connections
can be established in the future be-
tween American and Swedish water
works engineers through the exchange
of technical information and the ac-
tivities of professional organizations.

Corrosion Control With Calgon

By Owen Rice

A paper presented on Oct. 16, 1946, at the Southwest Section Meeting, Galveston, Tex., by Owen Rice, Calgon, Inc., Pittsburgh, Pa.

SOME years ago the announcement that from 0.5 to 2 ppm. of glassy phosphate * would prevent the precipitation of calcium carbonate from water was greeted with considerable skepticism. Water works engineers were quite willing to be shown, however, because of the many difficulties they were encountering with scale formation. A simple test, which could be performed within a few minutes in any laboratory, generally sufficed to allay this skepticism, and, consequently, it was not long before many hundreds of plants were using this glassy phosphate for this purpose, under such conditions that as many as several hundred parts per million of calcium carbonate would otherwise have been precipitated. These users included refineries and power plants, where it was necessary to keep scale formation from the condensers in the cooling systems, as well as municipal plants, where it is desirable to prevent after-precipitation of calcium carbonate in filters and pipelines, as well as the water heaters of the consumers.

Corrosion Control

The author's statements regarding the efficacy of this phosphate glass for

scale prevention were received with some skepticism, but there is no measuring the degree of unbelief which greeted his announcement that the same phosphate could be used for corrosion control. This could not be. Certainly, if a material prevented the precipitation of calcium carbonate, it should increase corrosion. For years almost everyone had relied on calcium carbonate for corrosion inhibition. The manufacturer was still glad to demonstrate but, unfortunately, the technique was not so easy as it had been with calcium carbonate precipitation.

It is not sufficient simply to put a nail or a weighed strip into a beaker of water containing a few parts per million of this glassy phosphate. If this is done, the specimen will rust just as rapidly as in untreated water, as shown in Fig. 1. Under quiescent conditions, that is, with no stirring— even at glassy phosphate concentrations of 200 ppm.—the steel rusts as rapidly in the treated water as in the untreated. If the water is stirred, however, a tremendous difference is at once apparent. The rate of corrosion in the untreated water is increased about 400 per cent, whereas the rate

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* Calgon is one of the many sodium phosphate glasses; it is characterized by a P_2O_5 content of 67 per cent. The glassy phosphate referred to in this paper is Calgon. The use

of other glassy phosphates, as well as most of the crystalline molecularly dehydrated phosphate, would yield results which were in qualitative but not quantitative agreement.

of corrosion in the water containing 25 ppm. of the phosphate glass is reduced about 75 per cent.

In quiescent waters, the supply of dissolved substances to the metal surface depends upon the relatively slow process of diffusion. Oxygen is supplied to the surface so slowly that the corrosion can proceed but slowly. Glassy phosphate is supplied to the surface so slowly that protective film formation proceeds at a practically negligible rate. Agitation greatly ac-

FIG. 1. Beaker Tests of Corrosion

celerates the rate at which oxygen is brought to the metal surface and thus permits a much faster rate of corrosion; in the ordinary untreated water just such an acceleration is observed. Agitation also accelerates the rate of supply of inhibitor to the metal surface and, thus, results in a much faster formation of a protective film. In the treated water, the increased rate of protective film formation more than compensates for the accelerative action of the increased rate of oxygen sup-

ply, with the net result that the corrosion rate decreases.

The concentrations used in the beaker tests admittedly are out of the question for a distribution system. But it is the rate of supply of the glassy phosphate to the metal surface that is the important factor, rather than the concentration alone. In flowing, treated water, phosphate is continuously being brought to the metal surface and, at any appreciable flow rate and phosphate dosage, it is obvious that considerably more of this phosphate will pass over the metal surface than was present in any of the small beakers. Figure 2 shows the results of tests in which the water is run through pipes at rates normal in practice; it is found that as little as 1 or 2 ppm. of metaphosphate is quite effective in reducing corrosion. In fact, the indications are that much of the apparently greater corrosion at the low phosphate dosages is simply due to the longer period of time required to form the protective film; the actual rate of corrosion at the end of five days is probably very little greater with only 2 ppm. of this glassy phosphate than with 10 ppm.

It might be noted that a higher rate of supply of the glassy phosphate is required for a given rate of protective film formation with a pickled surface than with the normal iron or steel surface. A pickled steel surface differs considerably in corrosive behavior from metal surfaces as they are generally encountered—that is, with a well developed oxide film. Thus, corrosion tests should be conducted on a surface similar to that encountered in actual use.

It should be emphasized that the linear flow velocity required for satisfactory corrosion protection with the

inhibitor is higher for small diameter pipe than for the actual distribution system. This factor should be taken into consideration in evaluating the results of many tests with phosphates (1). Apparently it is due to the development of turbulence at much lower linear velocities in large diameter pipes than in small. Turbulence greatly increases the rate of supply of inhibitor to the metal surface, and, therefore, the rate of protective film formation. Where very low flows are encountered in actual systems, as in bad "dead ends," frequent flushing is
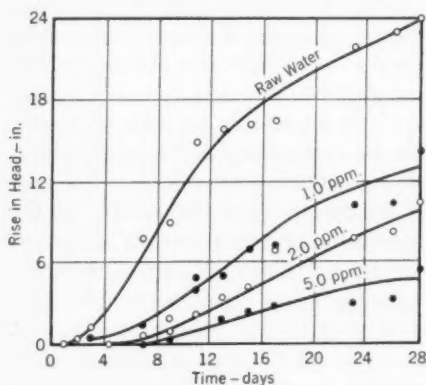
FIG. 2. Tests of Corrosion With Normal Flow

recommended until the protective film becomes well developed. Once the protective film has formed, a greatly reduced rate of supply of the glassy phosphate suffices to maintain the film, and flushing of the "dead end" can generally be eliminated.

In hot water, the percentage of protection obtained by the phosphate glass seems to be even higher than in cold water, but, even so, the conditions are so much more severe that, to do a really effective job of corrosion control, it is necessary to use concentrations of the order of 5 or 10 ppm. These higher concentrations are not

necessitated by reversion at the high temperatures, but by the effect, as illustrated by Fig. 3, which shows the effect of varying concentrations of metaphosphate at various temperatures. These tests covered a period of 8 hours in which the solution was not replenished with this glassy phosphate.

There is a pronounced hump in the corrosion curve which reaches a peak at approximately 80°C. Up to this point, the effect of temperature in ac-
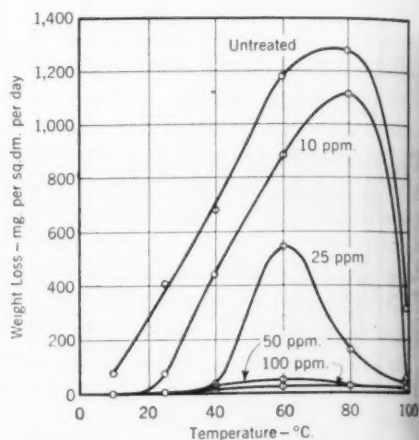
FIG. 3. Effect of Temperature Upon Corrosion

celerating the corrosive reaction is more pronounced than the opposing effect of the lowered oxygen concentration. Above this temperature, the lowered oxygen concentration has a greater effect than the increasing temperature, so that, at the atmospheric boiling point, the rate of corrosion is about the same as at room temperature. As the rate of corrosion in untreated water is less at the boiling point than at 80°C., there is not so rapid a loss of the phosphate due to adsorption on the iron oxide formed in the corrosion process. In other words, the rate of corrosion at the boiling point

is slower, so that with any given glassy phosphate concentration the protective film is laid down more rapidly than the rust is formed.

Stabilization of Iron and Manganese

A third application of this vitreous phosphate, which has attracted a great deal of attention, particularly in the municipal field, is its use to prevent the precipitation of dissolved iron from well water. Although not as spectacular as the use for the stabilization of

them separated and prevent their growth to such a size that they will cause noticeable discoloration of the water. This adsorption of the glassy phosphate upon the iron oxide particles is akin to the action of corrosion control, in which the formation of the protective film is due to the adsorption of this phosphate upon iron or iron oxide.

Figure 4 shows the effect of varying amounts of the phosphate in preventing the staining of clothes from a wa-
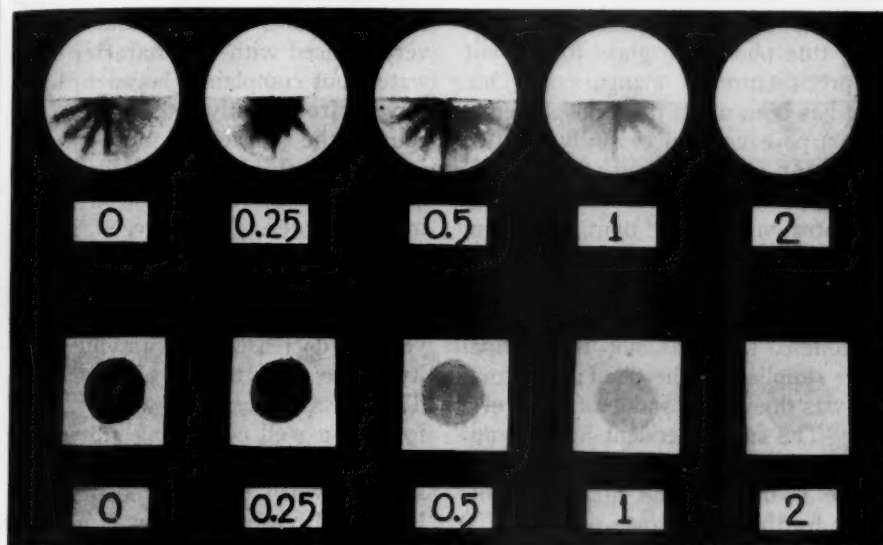
Fig. 4. Prevention of Iron Stain

calcium carbonate or for corrosion control, this application has been very beneficial in a number of plants, especially where harassed water works superintendents were receiving many "red water" complaints and were finding it difficult to correct the situation. The amount required for iron stabilization is 2 parts of the phosphate for each part of iron in the water. The adsorption of glassy phosphate on the particles of iron oxide tends to keep

ter containing iron. The stain is produced by filtering a liter of water containing 2 ppm. of iron through filter paper and cloth, and the figures indicate the ratio of the glassy phosphate to iron present in the water. For example, the amount of phosphate used for the cloth labelled "2" was actually 4 ppm., or twice the amount of iron present (as Fe). Such water treated with the vitreous phosphate will remain clear for a week or longer.

In the example illustrated, the water was allowed to run through the filters after having been exposed to the atmosphere for 48 hours.

Iron oxide is so extremely insoluble that it starts to separate the instant the ferrous iron present in the underground water supplies is oxidized to the ferric state. Consequently, it is vitally important that the glassy phosphate be added to the water before the iron is given an opportunity to oxidize, either through exposure to the air or treatment with chlorine.

Several municipal plants are also using this phosphate glass to prevent the precipitation of manganese. One plant has been using this phosphate for this purpose very successfully for five years. At another plant, the manganese reached the almost unheard-of concentration of 7.2 ppm., with an average of about 5 ppm., and virtually no complaints were received after the glassy phosphate treatment was begun. Of course, this was not the normal water supplied by the plant; the situation was due to the sudden failure of a well. The superintendent had the unfortunate experience of being informed of the change in the quality of his water by the appearance of some 200 angry women before his office door early on Tuesday morning. Many of them were waving their towels and tablecloths, which were covered with ugly brown spots and stains.

Treatment with 10 ppm. of this glassy phosphate was started the same week and continued for more than two years without any more such occurrences. At the end of that time, the superintendent finally succeeded in digging a new well and installing new pumping equipment, and was able to furnish a water which did not require such large phosphate dosages.

One other plant that has found this phosphate glassy phosphate useful for controlling custom the precipitation of dissolved iron is They of interest because it had already installed facilities for iron removal. As the ra it happens, the wells normally used by mission this plant contain only 0.5 to 0.8 ppm. vital t of iron, so that the installation of the Wh iron removal plant merely shifted the iron, area of complaints from "red water." ucts Formerly, the iron had precipitated near the plant and many complaints were received from residents in that section. After installation of the iron removal plant, these customers were very pleased with the character of the water, but complaints began to be received from outlying sections. Of course, the answer was obvious—the iron removal plant involved aeration and the aeration introduced oxygen into the water. This oxygen, in turn, rusted the pipes and caused the appearance of iron rust in the outlying sections. In addition, over a few years it decreased the carrying capacity of the pipes to a significant extent. The glassy phosphate was first used to treat a well containing 2.3 ppm. of iron which was sometimes used in the summer when the water demand was heavy. It worked so well that the plant engineers considered it desirable to treat the entire supply, with the result that complaints from all sections of the system were eliminated, and the carrying capacity of the distribution system was maintained.

Tuberculation Control

The fourth, and perhaps most important application of this phosphate glass, although it is really an outgrowth of its uses for corrosion control and for dissolved iron stabilization, is its use against tuberculation. The other applications of this vitreous phos- face si

phate are useful primarily to improve customer relations and good will. They are of relatively minor financial significance to the water plant, whereas the rate of tuberculation of the transmission lines and distribution mains is vital to any water works.

When iron rusts—whether it be cast iron, wrought iron, or steel—the products of corrosion take various forms

or there may be isolated attack at selected points. If the water is quite acid in nature, the metal may be simply dissolved, but at pH values above 5.0 some of the products of corrosion are left on the surface and only a part goes into the supply. Usually, the higher the pH value of the water, the greater the proportion of the corrosion products that are left on the surface of
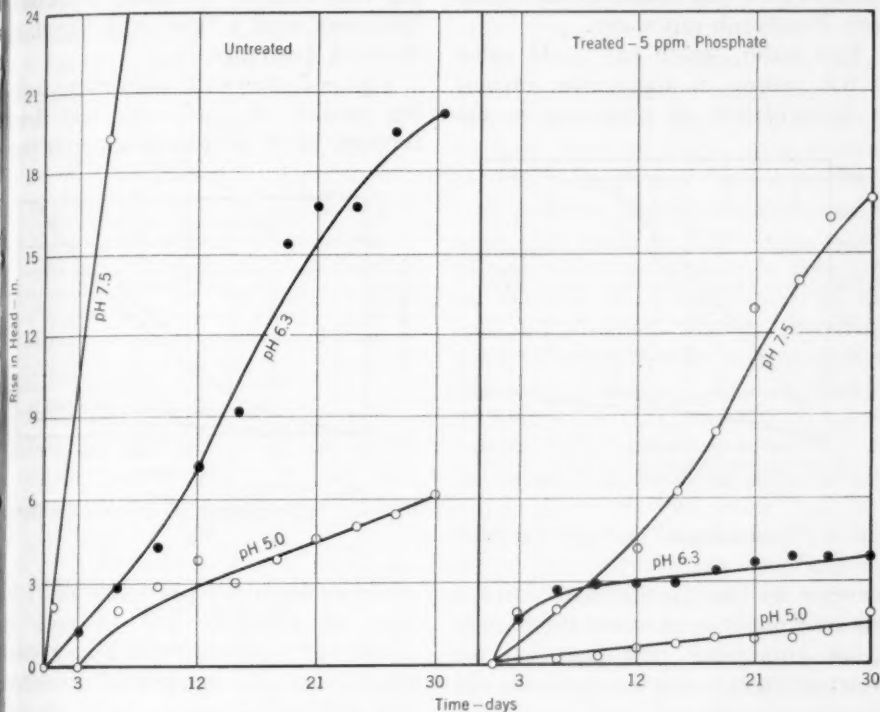
Fig. 5. Effect of pH Upon Tuberculation in Treated and Untreated Waters

and have various appearances and physical characteristics, depending upon the environment. Thus, in the air there is usually a general attack upon the surface resulting in a fairly uniform, rather adherent layer of rust over the entire surface. When the metal is submerged in water, there may be a general attack upon the surface similar to atmospheric corrosion

the metal and the more tendency there is for isolated attack. Thus there is a greater tendency to form tubercles in high pH water. These tubercules consist simply of corrosion products over the pits where the metal is dissolving.

Although treatment with lime and other alkalies has resulted in a great reduction, if not a complete elimination, of "red water" complaints in many

cities, its use has produced very little, if any, reduction in tuberculation. Usually, in fact, it has caused an increase. Treatment with the glassy phosphate, on the other hand, has always produced a marked reduction in the rate of tuberculation as well as in the rate of corrosion of a pipe as measured by pick-up in iron or weight loss from the metal. This is shown in Fig. 5, which gives the results of some tests with Pittsburgh tap water.

This water, which has a pH value of 6.3, causes an appreciable amount of tuberculation, as measured by the
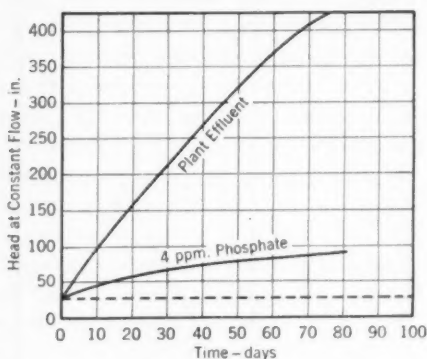
FIG. 6. Tuberculation Tests at Cincinnati

increase in head required to force a constant quantity of water through 20 ft. of ¼-in. black iron pipe. If the water is treated with lime or soda ash, so as to raise the pH value to only 7.5, the rate of tuberculation is increased tremendously—about 1,000 per cent. Incidentally, treatment of the water with acid (not shown in Fig. 5) caused an actual decrease in the rate of tuberculation, even though it increased the rate of attack upon the metal. Treatment of the water with the vitreous phosphate caused a marked drop in the rate of tuberculation, as well as in the rate of corrosion, at all pH values.

Figure 6 shows the results obtained by Mr. Evans, Supt., Municipal Water Purification Plant, Cincinnati, Ohio on the plant effluent with and without the addition of the glassy phosphate. This water is Ohio River water which after filtration, has been adjusted with lime to a pH value between 8.2 and 8.4. The marked effect of only 4 ppm of this vitreous phosphate in decreasing tuberculation is clearly apparent. The tests used a flow of 3.0 gpm. in 20 ft. of ¼-in. pipe.

Figure 7 shows the even more striking results obtained with test flow through 12 ft. of ½-in. black iron pipe
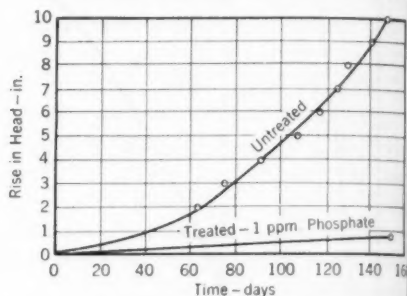
FIG. 7. Tuberculation Tests at Lynchburg Va.

of water having a pH value of 7, ppm. of alkalinity and 14 ppm. hardness. The use of this glassy phosphate practically stopped tuberculation and reduced corrosion—tests showed no iron pick-up in the mains—to the point where it is no longer a problem

The tests made by Peter E. Pal of the Hackensack Water Co. (2) are of considerable interest as they were conducted for over a year with a water of markedly different corrosive characteristics than that of Pittsburgh His method of evaluation of results included data for both weight loss and the head required to maintain a constant flow. The curves for a flow rate

of 5.4 gpm. through ¾-in. pipe are reproduced in Fig. 8.

It will be noted from these curves that the treated water caused a much greater weight loss for the first month than did the normal Hackensack water. As the curves show the cumulative rate of loss in weight as a function of the time, this high initial loss is reflected in all of the data for longer periods of exposure. After the first month of the test, the actual corrosion rate was very low—about 5 mg. per sq.dm. per day. This lower rate is

FIG. 8. Pipe Tests at Hackensack, N.J.

*Line No. 4 corrected to show weight loss after first month.

shown by the curve that has been added to show the rate at which the corrosion proceeded in the treated system after the first month.

What this means is that the glassy phosphate prevented the normal iron oxide film from forming on the pipe during the first month while, at the same time, with a rate of feed of only 2 ppm., it probably took the entire month for the protective film to form. Once formed, however, this film af-

forded a high degree of protection. Just how good this phosphate film is in protecting the pipe from corrosion is well illustrated by the fact that, at the end of the year, when the untreated water had formed a rust layer so thick on the inside of the pipe that it was practically plugged, it still was giving only one-fourth as much protection as the less than $\frac{1}{32}$ in. of deposit formed in the treated pipe which had caused only $\frac{1}{10}$ as much loss in head.

Of course, confirmatory data on an actual plant scale are much harder to secure and take a much greater period of time than do simple data relating to scale formation or "red water" and iron pick-up. Such full-scale tests as have been made to date over a period of years show a 50 per cent reduction in the rate of tuberculation as the least improvement that has been noticed. The greatest improvement noted has been an actual increase in the rate of flow—that is, a removal of tuberculation. Incredible as it may seem, this was effected without any increase in complaints of "red water." It was reported by the Underwriters Laboratories, whose engineers were making their regular survey of this city in order to determine the flow from the fire hydrants. The year after the use of this vitreous phosphate was started, they reported to the city manager that, for the first time in their experience, they had noticed an actual improvement in rate of flow over the values recorded in the previous year. The next year they noticed a still further improvement.

Many water works executives are faced with the problem of making an 8-in. main serve where a 10-in. main would normally be required. Others must contemplate laying new mains to handle additional suburban develop-

ments, unless the existing distribution system can be kept clean. Or the rate of depreciation of an entire existing system may be excessive, as the result of tuberculation. When the possibilities inherent in the use of the glassy phosphate for the maintenance of the carrying capacities of a distribution system are considered, its value may readily be appreciated.

Maintenance of carrying capacity is the most important feature of satis-

factory corrosion control. After a it is little consolation to know th corrosion in a system has been stoppe if it will no longer carry the water.

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2. PALLO, PETER E. A Study of Corrosi Control with Sodium Hexametapho phate. Jour. A.W.W.A., 38:499 (1946

Transportation Tax Exemption

The Revenue Act of 1943, effective June 1, 1944, continues in effect the exemption from payment of the transportation tax by states or their political subdivisions.

This means that water department employees may purchase tickets for any form of public transportation (where the tax applies; i.e. train, airplane, bus) without paying the 15 per cent federal tax, if the following conditions are met:

1. The travel must be recognized as official by the water department or city executive.

2. The official nature of the travel is, or will later be, evidenced by the payment (or reimbursement) of the amount paid for transportation.

3. The purchaser of the ticket or tickets presents to the agent of the common carrier a properly executed copy of Treasury Department form 731.

Copies of form 731 are obtainable from the various offices of the U.S. Internal Revenue Department. The completed form must be presented to the agent of the carrier when the ticket is purchased.

More complete information may be found in the JOURNAL for Sept. 1944, Vol. 36, page 1005.

Harry E. Jordan,
Secretary

Bactericidal Properties of Chlorine Dioxide

By G. M. Ridenour and R. S. Ingols

A contribution to the Journal by G. M. Ridenour, Associate Professor, and R. S. Ingols, Instructor, Public Health Engineering, Dept. of Environmental Health, School of Public Health, Univ. of Michigan, Ann Arbor, Mich.

THE usefulness of chlorine dioxide in producing a palatable water has been described by several investigators (1, 2). It appears that the material finds a special application where chlorine is either unsatisfactory or uneconomical in increasing palatability. Present practice with waters requiring disinfection in addition to taste and odor reduction, however, calls for the application of chlorine along with chlorine dioxide. Since chlorine dioxide is similar in reactive characteristics to chlorine, it would seem that it might be useful for disinfection, as well as for increasing palatability. In view of this possibility, studies have been made to learn whether this gas may also be useful as a bactericide.

Method of Study

The investigations undertaken compared the bactericidal effects of solutions of chlorine dioxide, chlorine and a mixture of the two in various substrates. These included: (1) naturally polluted river water, (2) artificially contaminated tap water, (3) artificially polluted solutions of peptone in water, (4) settled raw sewage, (5) activated sludge sewage effluent and (6) distilled water.

In addition, tests were made to determine the effect of hydrogen ion concentration on the efficiency of both chlorine dioxide and chlorine, by adjusting the pH of artificially polluted solutions of peptone and samples of naturally polluted river water.

The criterion used for the comparative effectiveness of the two gases as disinfectants was the presence or absence of bacterial growth after 30 minutes of contact with the chlorine dioxide or chlorine, indicated by transferring two 1-ml. portions of the treated material into tubes of lactose broth. These tubes were incubated at 37°C. and read at the end of 24 and 48 hours to check on possible recovery of the bacteria from the disinfection treatment. Simultaneously with the bacterial transfer, measurements were made of ortho-tolidine and ortho-tolidine-arsenite residuals in each sample.

Where artificial contaminants were used, a suspension of *Esch. coli* was prepared by seeding the entire surface of a freshly poured agar plate, incubating for 24 hours, and then washing off the surface with sterile water to form a suspension. A small volume of this suspension was added to the test sample. The final test sample contained approximately 2,500 organisms per ml. The effect of the disinfectants was measured on 100-ml. portions of the sample by adding solutions of varying amounts of chlorine dioxide, chlorine or a mixture of the two gases.

To confirm the absence of bacteriostasis in the method of testing used in

TABLE 1

Bactericidal Effects of Chlorine Dioxide, Chlorine and Mixture of Both in Different Media

Chlorine Dioxide				Chlorine				Mixture*			
Weight Applied ppm.	Residual (OT) ppm.	Residual (OTA) ppm.	Growth	Weight Applied ppm.	Residual (OT) ppm.	Residual (OTA) ppm.	Growth	Weight Applied ppm.	Residual (OT) ppm.	Residual (OTA) ppm.	Growth
Naturally Polluted Huron River Water											
3.8	0.10	0	++	2.0	0.25	trace	++	2.9	0.10	0	++
4.75	0.12	0	++	2.5	0.20	0.17	++	3.6	0.15	0	++
5.70	0.25	0.07	− −	3.0	0.50	0.25	− −	4.2	0.30	trace	++
6.65	0.40	0.10	− −	3.5	0.60	0.30	− −	5.1	0.20	trace	− −
7.60	0.50	0.12	− −	4.0	1.00	0.70	*− −	5.8	0.40	0.07	− −
8.55	1.0	0.30	− −	4.5	1.30	0.90	− −	6.5	0.60	0.10	− −
9.50	0.8	0.30	•	5.0	1.80	1.20	− −	7.2	0.80	0.15	− −
Artificially Contaminated Ann Arbor Tap Water											
0.095	0	0	++	0.05	0	0	++	0.07	0	0	++
0.19	trace	0	++	0.10	0	0	++	0.15	trace	0	++
0.38	0.05	0	−+	0.20	0.15	trace	++	0.29	0.05	0	++
0.76	0.10	0.05	−+	0.40	0.20	0.05	++	0.58	0.10	trace	++
1.14	0.20	0.07	− −	0.60	0.25	0.10	++	0.72	0.15	0.05	−+
1.52	0.20	0.10	− −	0.80	0.40	0.10	++	1.16	0.20	0.07	− −
1.90	0.30	0.12	− −	1.00	0.50	0.10	− −	1.50	0.30	0.07	− −
2.28	—	—		1.20	0.60	0.15	+−	1.70	0.30	0.10	− −
Artificially Contaminated Peptone Water (200 ppm.)											
7.6	0.1	0	++	6	1.0	trace	++				
9.5	0.9	trace	− −	7	1.5	0.05	++				
11.4	1.2	trace	− −	8	1.8	0.07	++				
13.3	1.7	0.3	− −	9	2.0	0.09	++				
15.2	1.7	0.5	− −	10	2.5	0.10	++				
17.1	2.5	0.9	− −	11	3.0	0.10	++				
19.0	3.0	1.2	− −	12	3.3	0.12	− −				
				13	3.5	0.15	− −				
Artificially Contaminated Peptone Water (400 ppm.)											
11.3	1.4	0	++	10	1.5	0.07	++	8.7	1.8	0	++
13.2	1.8	0	++	12	2.0	0.07	++	10.1	2.0	0	++
15.2	2.0	0.05	− −	14	2.5	0.08	++	11.6	2.5	0	++
17.1	2.5	0.07	− −	16	3.0	0.08	++	13.0	3.0	0.05	− −
19.1	3.0	0.20	− −	18	4.0	0.12	− −	14.5	3.5	0.07	− −
21.0	3.5	0.60	− −	20	4.5	0.15	− −	15.9	4.0	0.10	− −
23.0	3.5	0.80	− −	22	5.0	0.15	− −	17.4	4.5	0.12	− −

TABLE 1.—(Cont'd.)

Chlorine Dioxide				Chlorine				Mixture*			
Weight Applied ppm.	Residual (OT) ppm.	Residual (OTA) ppm.	Growth	Weight Applied ppm.	Residual (OT) ppm.	Residual (OTA) ppm.	Growth	Weight Applied ppm.	Residual (OT) ppm.	Residual (OTA) ppm.	Growth
Activated Sludge Sewage Plant Effluent											
0.95	0.25	0.05	++	0.5	0.05	trace	++	0.8	0.10	0.05	++
1.90	0.40	0.10	− −	1.0	0.20	0.10	− −	1.5	0.25	0.10	− −
2.80	0.50	0.20	− −	1.5	0.50	0.15	− −	2.2	0.50	0.15	− −
3.80	0.60	0.20	− −	2.0	0.90	0.20	− −	2.9	0.50	0.20	− −
Settled Raw Sewage											
7.6	0.0	0.0	++	4.0	0.0	0	++	5.8	0	0	++
11.4	0.0	0.0	++	6.0	0.0	0	++	8.9	0	0	++
15.2	0.3	0.0	++	8.0	0.0	0	++	11.6	0	0	++
19.0	1.0	trace	− −	10.0	trace	trace	− −	14.5	0	0	++
21.8	1.3	0.05	− −	12.0	0.3	trace	− −	16.9	0.05	0	++
26.6	1.5	0.10	− −	14.0	0.7	0.05	− −	20.3	0.15	trace	− −

* Chlorine to chlorine dioxide in 1:1.9 ratio.

these bactericidal studies, additional tests were set up on both chlorine and chlorine dioxide to determine possible inhibition by residuals not chemically measurable. These tests consisted of reinoculating, with *Esch. coli,* a portion of all chlorine and chlorine dioxide treated samples showing negative growth, incubating for 24 and 48 hours at 37°C. and observing growth. As the results of these bacteriostasis tests showed positive growth in all samples in 24 hours, it was considered unnecessary to de-chlorinate samples before transfer to the lactose broth.

All artificially constructed test waters, except those used in the pH studies, were buffered to a pH of 8.0 with 200 ppm. of sodium bicarbonate. The pH values of the river and sewage samples were between 7.5 and 8.0 with no buffer added. For the pH studies, the samples were adjusted with sodium

carbonate for a pH of 10, with sodium bicarbonate for a pH of 8.0, and with sodium di-hydrogen phosphate for a pH of 6.0.

All studies were carried out at room temperature (approximately 75°F.).

Results

The bactericidal effectiveness of chlorine dioxide in the various contaminated waters is shown in Tables 1 and 2. The relation of the disinfecting capacity of chlorine dioxide to that of chlorine and a mixture of chlorine and chlorine dioxide is given in these same tables. The standard ortho-tolidine (OT) and ortho-tolidine-arsenite (OTA) residuals given in these data were the residuals remaining after 30 minutes of contact with the media. The values for chlorine and chlorine dioxide dosages are shown on an actual weight basis.

Where mixtures of the two gases were used, the quantities applied were in a ratio of chlorine dioxide to chlorine of 1.9 to 1.0 by weight.

These results show that, regardless of the character or concentration of organic matter in the contaminated samples used for this study, chlorine dioxide was effective as a bactericide. The amounts required for disinfection varied with the type and concentration of the organic matter in the sample.

the artificially contaminated peptone waters, less chlorine dioxide than chlorine was needed on a weight basis. It is of interest to note that in all tests there was no consistent relationship between the OT residual and the bacterial kill. On the basis of OTA residuals, however, this relationship is comparatively exact, as, with one exception, less than 0.15 ppm. of OTA residual was sufficient in any sample with either disinfectant.

TABLE 2

Bactericidal Effects of Chlorine Dioxide, Chlorine and Mixture of Both in Different Media

Type of Pollution	Condition of Sample	Chlorine Dioxide			Chlorine			Mixture*		
		Weight Applied ppm.	Residual at Death Point		Weight Applied ppm.	Residual at Death Point		Weight Applied ppm.	Residual at Death Point	
			(OT) ppm.	(OTA) ppm.		(OT) ppm.	(OTA) ppm.		(OT) ppm.	(OTA) ppm.
Natural	Huron R.	5.7	0.40	0.10	3.00	0.50	0.25	6.5	0.60	0.10
Esch. coli	Ann Arbor tap water	1.1	0.20	0.07	1.00	0.50	0.10	1.2	0.20	0.07
Esch. coli	200 ppm. peptone	9.5	0.90	trace	12.00	3.30	0.12			
Esch. coli	400 ppm. peptone	15.2	2.00	0.05	20.00	4.50	0.15	13.0	3.00	0.05
Natural	Activated sludge effluent	1.9	0.40	0.10	1.00	0.20	0.10	1.5	0.25	0.10
Natural	Settled raw sewage	19.0	1.00	trace	10.00	trace	trace	20.3	0.15	trace
Esch. coli	Distilled water	0.8	0.10	0.05	1.00	0.50	0.10	1.1	0.20	0.07

* Chlorine to chlorine dioxide in 1:9 ratio.

This is illustrated in comparative form in Table 2, which shows the amount of chlorine dioxide, chlorine and the mixture of the two solutions required for bacterial kill. With no organic matter present, except that contained in the suspension, an application of 0.8 ppm. of the chlorine dioxide gave disinfection. The maximum initial dose required for raw settled sewage was 19 ppm. In comparison, the dosage required for chlorine was 10.0 ppm. In

OTA residuals obtained from chlorine dioxide are as effective in disinfection as those obtained from chlorine. In fact, lesser amounts, in general, of OTA residual were required from chlorine dioxide than from chlorine for an equal kill. The OTA residuals required to give kills with chlorine dioxide varied between 0.05 and 0.1 ppm., whereas 0.1 to 0.15 ppm. were required for chlorine. The average of all samples gave a required OTA re-

TABLE 3

Effects of Various pH Values Upon the Bactericidal Activity of Chlorine Dioxide and Chlorine in Different Media

pH 6				pH 8				pH 10			
Weight Applied *ppm.*	Residuals		Growth	Weight Applied *ppm.*	Residuals		Growth	Weight Applied *ppm.*	Residuals		Growth
	(OT) *ppm.*	(OTA) *ppm.*			(OT) *ppm.*	(OTA) *ppm.*			(OT) *ppm.*	(OTA) *ppm.*	
Chlorine Dioxide in River Water											
0.4	0.05	0	+ +	0.4	0.10	0	+ +	0.4	0.10	0	+ +
0.6	0.07	0	+ +	0.6	0.10	0	− −	0.6	0.12	0	+ +
0.8	0.10	0	+ +	0.8	0.15	0	− −	0.8	0.12	0	− −
1.0	0.10	0	− −	1.0	0.15	0	− −	1.0	0.15	0	− −
1.1	0.10	trace	− −	1.1	0.20	0	− −	1.1	0.15	0	− −
1.5	0.15	0.07	− −	1.5	0.20	0	− −	1.5	0.17	trace	− −
Chlorine in River Water											
0.6	0.05	0	+ +	1.0	0.15	0.05	+ +	2.0	0.5	0.05	+ +
0.8	0.10	0	+ +	2.0	0.25	0.05	− −	3.0	0.6	0.10	− −
1.0	0.15	trace	− −	3.0	0.30	0.10	− −	4.0	1.0	0.60	− −
1.2	0.25	trace	− −	4.0	0.40	0.10	− −	5.0	1.5	0.80	− −
Chlorine Dioxide in 50 ppm. Peptone Solution											
0.8	0	0.00	+ +	1.0	0	0	+ +	1.5	trace	0	+ +
1.5	0	0.00	+ +	1.9	0.1	0	+ +	2.3	0.2	0	+ +
2.3	0.05	0.00	− −	2.9	0.4	0.05	− −	3.0	0.3	0	− −
3.0	0.30	0.10	− −	3.8	0.8	0.20	− −	3.8	0.4	0.05	− −
3.8	0.70	0.3	− −	4.8	1.0	0.50	− −	4.6	0.5	0.10	− −
Chlorine in 50 ppm. Peptone Solution											
0.5	0.10	0	+ +	1.0	0.2	0	+ +	5.0	2.5	0.1	+ +
1.0	0.35	0	+ +	1.5	0.7	0	+ +	6.0	3.0	0.1	+ +
1.5	0.70	0.05	+ +	2.0	1.0	trace	+ +	7.0	3.5	0.15	+ +
2.0	1.20	0.07	+ −	2.5	1.2	0.05	− −	8.0	3.5	0.15	− −
2.5	1.50	0.08	− −	3.0	1.5	0.07	− −	9.0	4.0	0.2	− −
3.0	2.00	0.10	− −	3.5	2.0	0.10	− −	10.0	4.0	0.2	− −

sidual of less than 0.06 ppm. for chlorine dioxide and 0.12 ppm. for chlorine. The mixture of the chlorine and chlorine dioxide gave intermediate results.

The influence of hydrogen ion concentration on the bactericidal properties of chlorine dioxide is given in Tables 3 and 4, showing results on a contaminated natural water low in organic matter, and on an artificially contaminated water containing 50 ppm. of peptones, each adjusted to pH values of 6, 8 and 10. These data show that the bactericidal efficiency of chlorine dioxide was only slightly affected

by the lower hydrogen ion concentrations (higher pH values). In the natural waters an application of 1.0 ppm. of chlorine dioxide by weight gave complete kill at pH 6.0, 0.6 ppm. initial dosage at pH 8.0, and 0.8 ppm. at pH 10.0. The peptone water required 2.3 ppm. at pH 6.0, 2.9 ppm. at pH 8.0, and 3.0 ppm. at pH 10.0; a slight increase in dosage being required at the higher pH. It was noteworthy, however, that the dosage required at pH 10.0, compared to that at pH 6.0, although only slightly greater for chlorine dioxide, was two

waters. In waters of lesser pollution even less residual was required for the same contact period. The OTA residuals required from chlorine were as great or slightly greater. On the basis of relative weights of the two gases, more or less chlorine dioxide was required than chlorine for equal OTA residuals, depending on the amount, type and concentration of organic matter present. For example, with chlorine dioxide doses of 1.9 times the chlorine, kills were almost identical on all waters that had not been artificially contaminated. On waters heavily

TABLE 4

Summary of Effect of pH on Required Bactericidal Concentrations of Chlorine Dioxide and Chlorine

Substrate	Disin-fectant	pH 6			pH 8			pH 10		
		Weight Applied ppm.	Residual		Weight Applied ppm.	Residual		Weight Applied ppm.	Residual	
			(OT) ppm.	(OTA) ppm.		(OT) ppm.	(OTA) ppm.		(OT) ppm.	(OTA) ppm.
River water	ClO$_2$	1.0	0.10	0	0.6	0.10	0	0.8	0.1	0
River water	Cl	1.0	0.15	trace	2.0	0.25	0.05	3.0	0.6	0.10
Peptone solution*	ClO$_2$	2.3	0.05	0	2.9	0.40	0.05	3.0	0.3	0
Peptone solution*	Cl	2.5	1.50	0.08	2.5	1.20	0.05	8.0	3.5	0.15

* 50 ppm.

to three times as great for chlorine in both river and peptone waters.

Discussion

Bactericidal Properties of Chlorine Dioxide

These investigations indicate that chlorine dioxide is an effective bactericidal material for disinfection of contaminated waters, equal to chlorine on the basis of OTA residuals after 30 minutes' contact. In general, 0.1 ppm. of OTA residual from chlorine dioxide for 30 minutes seems to be adequate for the more heavily polluted

dosed with artificial organic matter (peptone), less chlorine was required in the form of chlorine dioxide than as elemental chlorine.

Effect of pH on Bactericidal Efficiency of Chlorine Dioxide

An important property of chlorine dioxide in disinfection is shown by failure of pH to affect materially the bactericidal efficiency, as illustrated in Table 4. This characteristic is in marked contrast to the well-known effect of pH on the efficacy of chlorine. Whereas the disinfecting efficiency of

chlorine decreases as the pH rises, chlorine dioxide disinfection is relatively unchanged. The reason for this difference appears to lie in the differences in the degree of hydrolysis of chlorine and chlorine dioxide. Chlorine hydrolyzes readily to form hypochlorous acid and hydrochloric acid. At higher pH values alkaline hypochlorites are formed, thus reducing the hypochlorous acid concentration. Chlorine dioxide, on the other hand, hydrolyzes to a limited extent only, and the effect of the hydrogen ion is, therefore, of relatively minor importance.

This greater—and stable—killing power of chlorine dioxide at higher pH (up to pH 10.0 or more) has important potential applications, such as the disinfection of highly alkaline waters, waters conditioned to high pH to prevent corrosion, or softening plant effluents.

Conclusions

From the experimental laboratory, evidence obtained from studies on the bactericidal properties of chlorine dioxide, in comparison to chlorine, indicates the following conclusions:

1. On the basis of ortho-tolidine-arsenite (OTA) residuals, the bactericidal properties of chlorine dioxide are as great as, if not slightly greater than, chlorine. An OTA residual of less than 0.1 ppm. was sufficient to disinfect the most heavily polluted water used in this investigation. *With waters not artificially contaminated, less chlorine than chlorine dioxide, by weight, was needed to kill. In the presence of high concentrations of peptone, less chlorine dioxide than chlorine was required for kill. Mixtures of the two gases give intermediate results.*

2. In contrast to chlorine, the bactericidal efficiency of chlorine dioxide is relatively unaffected by pH values between 6.0 and 10.0. This would indicate important applications in waters of high natural alkalinity, those treated to prevent corrosion and softened waters.

Acknowledgment

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EDITOR'S NOTE. *The research work done by the authors is highly important, for the effect of chlorine dioxide upon the rate of disinfection has a bearing upon its broad applicability for water treatment.*

Certain details of the work need further study. If the OTA determinations were carried out at 75°F., as implied by the authors, the results may need re-inspection, for it is now known that OTA determinations become less accurate if made at temperatures above 60–70°F. As rapid advances in the understanding of the process of free residual chlorination have been made since this study was carried out, it is hoped that the authors or others will re-examine the questions which the authors set out to answer.

Analysis of Pipe Flow Formulas in Terms of the Darcy Function f

By Leo Hudson

A contribution to the Journal by Leo Hudson, Hydraulic Engr., Sykesville, Md.

IT is believed that this analysis of pipe flow formulas justifies the establishment of the Williams-Hazen formula for general use in the design of water pipelines in terms of the proper values of f in the Darcy formula. The main tables (Table 1) give the values of f comparable to the Williams-Hazen C coefficients. Thus the objections to the Williams-Hazen formula are largely removed, but the advantages of these well-known coefficients are retained.

The dimensional coefficients C are translated to the dimensionless coefficients f, thereby facilitating the direct account of the effect of pipe roughness. The complicated Williams-Hazen formula is reduced to the more simple form of the Darcy formula to give the same results.

Table 1 gives the values of f and the friction head loss per 100 ft. of 4- to 144-in. pipe with equivalent C values of 100, 110, 120, 130, 140 and 150 for mean velocities of 1, 2, 3, 4, 5 and 6 fps., as well as comparable values of n in the Manning and Kutter formulas. Table 2 gives the conversion factors for the friction loss per 100 ft. of pipe and for f comparable to values of C from 40 to 160. The data relate the Williams-Hazen formula to the Reynolds parameter **R**. Figure 1 seems to justify the conclusion that, for pipeline designing, the Manning, Kutter and Fanning formulas are misapplied and should be abandoned.

It is true that the values of f listed do not take into consideration the temperature of the water, but they are comparable to a temperature of 50°F. Variations in the temperature will be overcome by practical considerations, and the designing engineer will seldom have to notice water temperature in ordinary transmission and distribution system pipelines. At such times as they might be significant, reference may be made to Fig. 2. This statement does not apply to pipelines for more viscous liquids, for which the Reynolds parameter is essential.

This analysis is not immediately concerned with the application of C to different kinds of pipe and different qualities of water, for most engineers have well-formed opinions of the application of such coefficients. A study of Fig. 1, however, may be of interest for this application.

It is hoped that this analysis will aid engineers generally in reaching a consistent standard which will enable them to use a common language for pipeline problems. If it does not, however, it will at least furnish a basis for a ready comparison.

Finally, what is done here is to give a table of f values to be used in the

Darcy formula, varied according to C in the Williams-Hazen formula. These values of f used in connection with the Reynolds number provide a parameter by which k may be measured in feet. The semi-empirical equation by Colebrook is asymptotic to both smooth pipe and rough pipe equations. This is the basis for Fig. 2.

Analysis of Formulas

The Chezy Formula:

$$V = C\sqrt{Rs} \dots \dots (1)$$

was evolved in 1775 and is a purely empirical formula (see "List of Symbols" at end of paper). It was originally intended for open channels but was afterward used for pipelines, gravity lines flowing partially full and pipelines flowing full under pressure. This formula is of the exponential type and may be expressed as:

$$V = CR^{\frac{1}{2}}s^{\frac{1}{2}} \dots \dots (2)$$

The present-day objection to all formulas of the exponential type is that C is a discharge coefficient rather than a resistance coefficient. As it bears a reciprocal relationship to f:

$$C = \sqrt{\frac{8g}{f}}, \quad \text{or} \quad f = \frac{8g}{C^2}$$

C is obviously not dimensionless.

In 1857 Darcy rearranged the Chezy formula in terms of the coefficient f, which is dimensionless. It is easy enough to prove that the two arrangements give the same results. The Darcy equation is:

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \dots \dots (3)$$

in which $f = \dfrac{8g}{C^2}$, but this relationship is true only when the exponents are

the same as they are in the Chezy formula and is not to be assumed for all exponential formulas.

In 1869 Kutter devised an expression for C intended originally for open channels, but this coefficient has been extensively used for pipelines flowing partially full (which are open channels in one sense of the word) and generally used for gravity lines and sewers. The Kutter coefficient is:

$$C = \frac{41.65 + \dfrac{1.811}{n} + \dfrac{0.00281}{s}}{1 + \dfrac{n}{\sqrt{R}}\left(41.65 + \dfrac{0.00281}{s}\right)} \dots (4)$$

This is a complicated expression, but it is easily solved by assuming or determining the values for s. The coefficient is the same for all slopes when $R = 3.28$ ft., or 1 m. Above a 1 per cent grade, C remains practically constant for any one size pipe and for any one value of n. For all practical purposes, and for pipe up to 20 ft. in diameter and grades greater than 0.05 per cent, the equation may be written:

$$C = \frac{41.65 + \dfrac{1.811}{n}}{\left(1 + \dfrac{n}{\sqrt{R}}\right)41.65} \dots (5)$$

For reasons given further on, the Chezy formula in terms of the Kutter C is considered a misapplication for pipelines under any conditions and as such is abandoned (Fig. 1).

In 1890 Manning evolved a simplified form for the Kutter formula and recommended it for pipelines as well as open channels. The Manning formula is:

$$V = \frac{1.486}{n} R^{\frac{1}{2}}s^{\frac{1}{2}} \dots \dots (6)$$

It is frequently stated that the "n"

Fig. 1. Comparative Curves for *f* Values at a Mean Velocity of 3 fps.
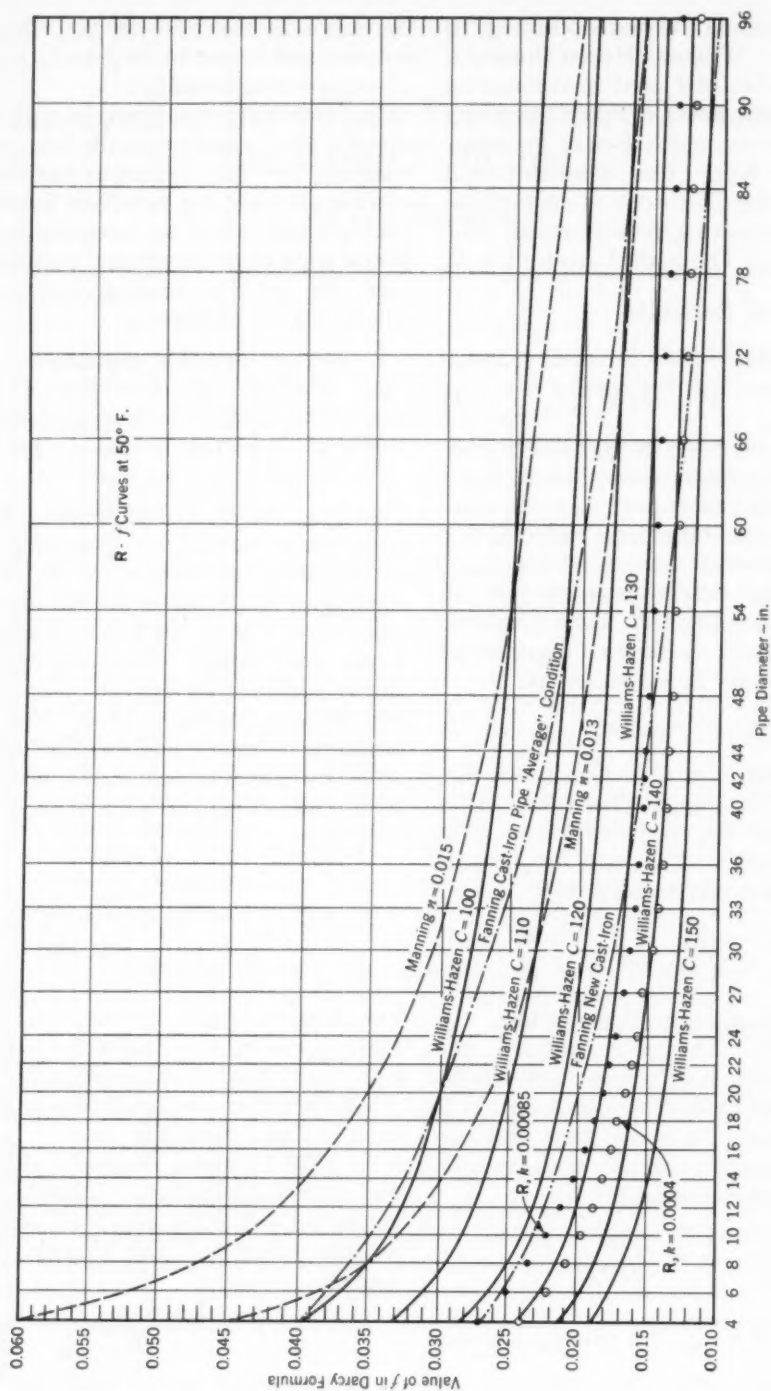
FIG. 1. Comparative Curves for f Values at a Mean Velocity of 3 fps.

in the Manning formula (Eq. 6) is the same as the "n" in the Kutter formula (Eq. 4), but this is not so, although they are nearly the same. The 1.486 factor is merely the cube root of one meter (3.28 ft.), and for accuracy in chain calculations should be expressed as 1.4862. The Manning formula (Eq. 6) gives an expression for the true C in the Chezy formula, however, when it is expressed:

$$V = \frac{1.4862}{n} R^{\frac{1}{6}} \sqrt{Rs} \ldots \ldots (7)$$

The coefficient then is equal to $\frac{1.4862}{n} R^{\frac{1}{6}}$, which bears a relation to f in the expression $f = \frac{8g}{C^2}$.

The Manning formula may be used in developing the relation of C to f and, solving in terms of s:

$$s = \left[0.4527345n^2 \frac{1}{R^{\frac{4}{3}}} \right] V^2 \ldots (8)$$

In 1905 the Williams-Hazen formula was evolved, going back to the exponential form:

$$V = CR^{0.63}s^{0.54}0.001^{-0.04} \ldots (9)$$

The constant $0.001^{-0.04}$ is equal to 1.318256. Solving for s:

$$s = 0.599484 \frac{V^{1.852}}{C^{1.852}R^{1.17}} \ldots (10)$$

and $s \times 100 = H_f$, or friction head loss per 100 ft. of pipe. H_f for 100 ft. of pipe is used because, for gravity lines and sewers, the value of H_f is equal to the required percentage of grade.

It is often desired to know what value of n in the Manning formula should be assumed to arrive at the comparable C in the Williams-Hazen formula. Substituting the value of s

in the Manning formula (Eq. 6) for the value of s in the Williams-Hazen formula (Eq. 9) and solving for n:

$$n = 1.15 \frac{\frac{R^{0.09}}{1.08}}{\frac{0.08}{V^{1.08}} \frac{1}{C^{1.08}}} \ldots \ldots (11)$$

By the above equation, the comparable values of n were calculated and are shown in Table 1. The value of n for any one velocity and any one size pipe is inversely proportional to the $\frac{1}{1.08}$ power of C.

Many other exponential formulas have been evolved, but of all the Williams-Hazen formula is most extensively used by engineers. The Scobey formulas have much merit, and one takes into consideration the temperature of the water. The ultimate purpose of this analysis is to select the one formula now in most general use, reduce it to the Darcy form in terms of the dimensionless f and relate the values of f to the R-f formula best suited for that purpose.

Reynolds Number Parameter

The Reynolds number $\mathbf{R} = \frac{VD}{\nu}$ where V is the mean velocity of the flow in feet per second, D is the internal diameter of the pipe in feet and ν is the coefficient of kinematic viscosity of the fluid in square feet per second. The coefficient f in the Darcy formula is a dimensionless quantity, and, at ordinary velocities, is a function of two other dimensionless quantities: the relative roughness of the pipeline surface and the Reynolds number $\mathbf{R}$. The kinematic viscosity depends upon the temperature of the fluid. During the last twenty years great progress has been made in the study of fluid flows in terms of the viscosity of the

TABLE 1

$\dfrac{V^2}{2g} = 0.0155$ ft.

H_f = friction loss per 100 ft.

$V = 1$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D \begin{cases} \text{in.} \\ \text{ft.} \end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q \begin{cases} \text{cfs.} \\ \text{mgd.} \end{cases}$
4 0.333	H_f n f	0.2144 0.0132 0.0461	0.1797 0.0120 0.0386	0.1529 0.0111 0.0329	0.1319 0.0103 0.0283	0.1149 0.0096 0.0247	0.1020 0.0090 0.0218	0.087 0.0562
6 0.500	H_f n f	0.1339 0.0136 0.0432	0.1122 0.0125 0.0362	0.0955 0.0115 0.0308	0.0823 0.0107 0.0266	0.0718 0.0100 0.0232	0.0632 0.0094 0.0204	0.196 0.1267
8 0.667	H_f n f	0.0956 0.0139 0.0411	0.0801 0.0128 0.0344	0.0682 0.0118 0.0293	0.0588 0.0109 0.0253	0.0512 0.0102 0.0220	0.0451 0.0096 0.0194	0.349 0.2256
10 0.833	H_f n f	0.0737 0.0142 0.0396	0.0618 0.0130 0.0332	0.0525 0.0120 0.0282	0.0453 0.0111 0.0244	0.0395 0.0104 0.0212	0.0348 0.0098 0.0187	0.545 0.3522
12 1.000	H_f n f	0.0594 0.0144 0.0383	0.0498 0.0132 0.0321	0.0424 0.0122 0.0273	0.0365 0.0113 0.0236	0.0318 0.0106 0.0205	0.0280 0.0099 0.0181	0.785 0.5074
14 1.167	H_f n f	0.0497 0.0146 0.0374	0.0416 0.0134 0.0313	0.0354 0.0123 0.0267	0.0306 0.0115 0.0230	0.0266 0.0107 0.0200	0.0235 0.0100 0.0177	1.069 0.6910
15 1.250	H_f n f	0.0459 0.0147 0.0370	0.0385 0.0134 0.0310	0.0327 0.0124 0.0264	0.0282 0.0115 0.0228	0.0246 0.0108 0.0198	0.0217 0.0101 0.0175	1.227 0.7930
16 1.333	H_f n f	0.0426 0.0148 0.0366	0.0357 0.0135 0.0307	0.0304 0.0125 0.0261	0.0262 0.0116 0.0225	0.0228 0.0108 0.0196	0.0201 0.0101 0.0173	1.396 0.9023
18 1.500	H_f n f	0.0371 0.0149 0.0359	0.0311 0.0137 0.0301	0.0265 0.0126 0.0256	0.0228 0.0117 0.0221	0.0199 0.0109 0.0192	0.0175 0.0102 0.0169	1.767 1.1420
20 1.667	H_f n f	0.0327 0.0150 0.0352	0.0274 0.0138 0.0295	0.0233 0.0127 0.0251	0.0201 0.0118 0.0216	0.0175 0.0110 0.0189	0.0154 0.0103 0.0166	2.182 1.4103
22 1.833	H_f n f	0.0294 0.0152 0.0347	0.0246 0.0139 0.0291	0.0210 0.0128 0.0247	0.0181 0.0119 0.0213	0.0158 0.0111 0.0186	0.0139 0.0104 0.0164	2.630 1.6998
24 2.000	H_f n f	0.0267 0.0153 0.0342	0.0224 0.0140 0.0286	0.0190 0.0129 0.0244	0.0164 0.0120 0.0210	0.0143 0.0112 0.0183	0.0126 0.0105 0.0161	3.142 2.0307
$D \begin{cases} \text{in.} \\ \text{ft.} \end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q \begin{cases} \text{cfs.} \\ \text{mgd.} \end{cases}$

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.0155$ ft.

H_f = friction loss per 100 ft.

$$V = 1 \text{ fps.}$$

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D \begin{cases} \text{in.} \\ \text{ft.} \end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q \begin{cases} \text{cfs.} \\ \text{mgd.} \end{cases}$
27 2.250	H_f n f	0.0233 0.0154 0.0338	0.0195 0.0141 0.0283	0.0166 0.0130 0.0241	0.0143 0.0121 0.0208	0.0125 0.0113 0.0181	0.0110 0.0106 0.0160	3.976 2.5698
30 2.500	H_f n f	0.0205 0.0156 0.0330	0.0172 0.0142 0.0277	0.0146 0.0131 0.0235	0.0126 0.0122 0.0203	0.0110 0.0114 0.0177	0.0097 0.0107 0.0156	4.909 3.1728
33 2.750	H_f n f	0.0183 0.0157 0.0324	0.0153 0.0144 0.0272	0.0130 0.0132 0.0231	0.0113 0.0123 0.0199	0.0098 0.0115 0.0174	0.0086 0.0108 0.0153	5.940 3.8391
36 3.000	H_f n f	0.0166 0.0158 0.0321	0.0139 0.0145 0.0269	0.0118 0.0133 0.0229	0.0102 0.0124 0.0197	0.0089 0.0116 0.0172	0.0078 0.0109 0.0152	7.069 4.5688
40 3.333	H_f n f	0.0146 0.0159 0.0315	0.0122 0.0146 0.0264	0.0104 0.0135 0.0225	0.0090 0.0125 0.0194	0.0078 0.0117 0.0169	0.0069 0.0110 0.0149	8.727 5.4465
42 3.500	H_f n f	0.0138 0.0160 0.0312	0.0116 0.0146 0.0261	0.0098 0.0135 0.0222	0.0085 0.0125 0.0192	0.0074 0.0117 0.0167	0.0065 0.0110 0.0147	9.621 6.2182
44 3.670	H_f n f	0.0130 0.0161 0.0309	0.0109 0.0147 0.0259	0.0093 0.0136 0.0220	0.0080 0.0126 0.0190	0.0070 0.0118 0.0166	0.0061 0.0110 0.0146	10.524 6.8018
48 4.000	H_f n f	0.0118 0.0162 0.0305	0.0099 0.0148 0.0256	0.0084 0.0137 0.0217	0.0073 0.0127 0.0188	0.0063 0.0118 0.0163	0.0056 0.0111 0.0144	12.566 8.122
54 4.500	H_f n f	0.0103 0.0164 0.0300	0.0086 0.0150 0.0251	0.0073 0.0138 0.0214	0.0063 0.0128 0.0185	0.0055 0.0120 0.0161	0.0049 0.0112 0.0142	15.904 10.279
60 5.000	H_f n f	0.0092 0.0165 0.0294	0.0077 0.0151 0.0246	0.0066 0.0139 0.0210	0.0057 0.0129 0.0181	0.0049 0.0121 0.0158	0.0043 0.0113 0.0139	19.635 12.690
66 5.500	H_f n f	0.0082 0.0166 0.0289	0.0068 0.0152 0.0242	0.0058 0.0140 0.0206	0.0050 0.0130 0.0178	0.0044 0.0122 0.0155	0.0039 0.0114 0.0136	23.758 15.355
72 6.000	H_f n f	0.0074 0.0167 0.0285	0.0062 0.0153 0.0239	0.0053 0.0141 0.0203	0.0046 0.0131 0.0175	0.0040 0.0123 0.0153	0.0035 0.0115 0.0135	28.274 18.274
$D \begin{cases} \text{in.} \\ \text{ft.} \end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q \begin{cases} \text{cfs.} \\ \text{mgd.} \end{cases}$

TABLE 1 (contd.)

$\frac{V^2}{2g} = 0.0155$ ft.

H_f = friction loss per 100 ft.

$V = 1$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$
78 6.500	H_f n f	0.0067 0.0168 0.0280	0.0056 0.0154 0.0235	0.0048 0.0142 0.0200	0.0041 0.0132 0.0172	0.0036 0.0123 0.0150	0.0032 0.0116 0.0132	33.183 21.447
84 7.000	H_f n f	0.0061 0.0169 0.0278	0.0051 0.0155 0.0233	0.0043 0.0143 0.0198	0.0038 0.0133 0.0171	0.0033 0.0124 0.0149	0.0029 0.0117 0.0131	38.485 24.874
90 7.500	H_f n f	0.0057 0.0170 0.0275	0.0048 0.0156 0.0230	0.0041 0.0144 0.0196	0.0035 0.0134 0.0169	0.0031 0.0125 0.0147	0.0027 0.0117 0.0130	44.179 28.554
96 8.000	H_f n f	0.0053 0.0172 0.0273	0.0044 0.0157 0.0229	0.0038 0.0145 0.0195	0.0033 0.0135 0.0168	0.0028 0.0126 0.0146	0.0025 0.0118 0.0129	50.265 32.487
102 8.500	H_f n f	0.0049 0.0172 0.0269	0.0041 0.0158 0.0225	0.0035 0.0146 0.0192	0.0030 0.0135 0.0165	0.0026 0.0126 0.0144	0.0023 0.0118 0.0127	56.745 36.675
108 9.000	H_f n f	0.0046 0.0173 0.0267	0.0039 0.0159 0.0224	0.0033 0.0146 0.0190	0.0028 0.0136 0.0164	0.0025 0.0127 0.0143	0.0022 0.0119 0.0126	63.617 41.117
114 9.500	H_f n f	0.0043 0.0174 0.0264	0.0036 0.0159 0.0221	0.0031 0.0147 0.0188	0.0027 0.0136 0.0163	0.0023 0.0127 0.0142	0.0020 0.0119 0.0125	70.882 45.812
120 10.000	H_f n f	0.0041 0.0175 0.0262	0.0034 0.0160 0.0220	0.0029 0.0147 0.0187	0.0025 0.0137 0.0161	0.0022 0.0128 0.0140	0.0019 0.0120 0.0124	78.540 50.762
126 10.500	H_f n f	0.0039 0.0175 0.0260	0.0032 0.0161 0.0218	0.0028 0.0148 0.0185	0.0024 0.0138 0.0160	0.0021 0.0128 0.0139	0.0018 0.0120 0.0123	86.590 55.965
132 11.000	H_f n f	0.0036 0.0176 0.0257	0.0030 0.0161 0.0215	0.0026 0.0149 0.0183	0.0022 0.0138 0.0158	0.0020 0.0129 0.0138	0.0017 0.0121 0.0121	95.033 61.421
138 11.500	H_f n f	0.0035 0.0177 0.0256	0.0029 0.0162 0.0214	0.0025 0.0149 0.0182	0.0021 0.0139 0.0157	0.0019 0.0129 0.0137	0.0016 0.0121 0.0120	103.869 67.132
144 12.000	H_f n f	0.0033 0.0177 0.0254	0.0028 0.0162 0.0213	0.0023 0.0150 0.0181	0.0020 0.0139 0.0156	0.0018 0.0130 0.0136	0.0015 0.0122 0.0119	113.097 73.100
$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$

TABLE 1 (contd.)

$\frac{V^2}{2g} = 0.0622$ ft.

H_f = friction loss per 100 ft.

$V = 2$ fps.

Area A (sq.ft.) $= \dfrac{Q\ \text{(cfs.)}}{V\ \text{(fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

(cfs.) (fps.) gpm.	$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$
3.183 1.447	4 0.333	H_f n f	0.7763 0.0125 0.0416	0.6505 0.0114 0.0349	0.5535 0.0106 0.0297	0.4774 0.0098 0.0256	0.4161 0.0091 0.0223	0.3664 0.0086 0.0196	0.174 0.1124
8.485 24.874	6 0.500	H_f n f	0.4839 0.0129 0.0389	0.4055 0.0118 0.0326	0.3450 0.0109 0.0277	0.2976 0.0101 0.0239	0.2594 0.0095 0.0209	0.2284 0.0089 0.0184	0.392 0.2534
44.179 28.554	8 0.667	H_f n f	0.3461 0.0132 0.0371	0.2900 0.0121 0.0311	0.2468 0.0112 0.0265	0.2129 0.0104 0.0228	0.1855 0.0097 0.0199	0.1634 0.0091 0.0175	0.698 0.4512
50.265 32.487	10 0.833	H_f n f	0.2665 0.0135 0.0357	0.2233 0.0123 0.0299	0.1900 0.0114 0.0254	0.1639 0.0106 0.0220	0.1428 0.0099 0.0191	0.1258 0.0093 0.0169	1.090 0.7044
56.745 36.675	12 1.000	H_f n f	0.2152 0.0137 0.0346	0.1803 0.0125 0.0290	0.1534 0.0116 0.0247	0.1323 0.0107 0.0213	0.1153 0.0100 0.0185	0.1016 0.0094 0.0163	1.570 1.0148
63.617 41.117	14 1.167	H_f n f	0.1796 0.0139 0.0337	0.1505 0.0127 0.0282	0.1281 0.0117 0.0240	0.1105 0.0109 0.0207	0.0963 0.0102 0.0181	0.0848 0.0095 0.0159	2.138 1.3820
70.882 45.812	15 1.250	H_f n f	0.1662 0.0139 0.0334	0.1393 0.0128 0.0280	0.1185 0.0118 0.0238	0.1022 0.0109 0.0205	0.0891 0.0102 0.0179	0.0784 0.0096 0.0158	2.454 1.5860
78.540 50.762	16 1.333	H_f n f	0.1543 0.0140 0.0330	0.1293 0.0128 0.0277	0.1100 0.0118 0.0235	0.0949 0.0110 0.0203	0.0827 0.0103 0.0177	0.0728 0.0096 0.0156	2.792 1.8046
86.590 55.965	18 1.500	H_f n f	0.1344 0.0142 0.0324	0.1126 0.0129 0.0272	0.0958 0.0119 0.0231	0.0827 0.0111 0.0199	0.0720 0.0104 0.0174	0.0634 0.0097 0.0153	3.534 2.2840
95.033 61.421	20 1.667	H_f n f	0.1187 0.0143 0.0318	0.0995 0.0131 0.0266	0.0846 0.0120 0.0227	0.0730 0.0112 0.0196	0.0636 0.0105 0.0170	0.0560 0.0098 0.0150	4.364 2.8206
103.869 67.132	22 1.833	H_f n f	0.1064 0.0144 0.0313	0.0892 0.0132 0.0262	0.0759 0.0121 0.0223	0.0654 0.0113 0.0192	0.0570 0.0105 0.0168	0.0502 0.0099 0.0148	5.260 3.3996
113.097 73.100	24 2.000	H_f n f	0.0961 0.0145 0.0309	0.0805 0.0133 0.0259	0.0685 0.0122 0.0220	0.0591 0.0114 0.0190	0.0515 0.0106 0.0166	0.0454 0.0100 0.0146	6.284 4.0614
$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$	$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$

TABLE 1 (contd.)

$\frac{V^2}{2g} = 0.0622$ ft.

H_f = friction loss per 100 ft.

$$V = 2 \text{ fps.}$$

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$
27 2.250	H_f n f	0.0840 0.0146 0.0304	0.0704 0.0134 0.0255	0.0599 0.0124 0.0217	0.0517 0.0115 0.0187	0.0450 0.0107 0.0163	0.0396 0.0101 0.0143	7.952 5.1396
30 2.500	H_f n f	0.0739 0.0148 0.0297	0.0619 0.0135 0.0249	0.0527 0.0125 0.0212	0.0454 0.0116 0.0183	0.0396 0.0108 0.0159	0.0349 0.0101 0.0140	9.818 6.3456
33 2.750	H_f n f	0.0661 0.0149 0.0292	0.0554 0.0136 0.0245	0.0471 0.0126 0.0208	0.0407 0.0117 0.0180	0.0354 0.0109 0.0158	0.0312 0.0102 0.0138	11.880 7.6782
36 3.000	H_f n f	0.0597 0.0150 0.0288	0.0500 0.0137 0.0241	0.0426 0.0127 0.0205	0.0367 0.0118 0.0177	0.0320 0.0110 0.0154	0.0282 0.0103 0.0136	14.138 9.1376
40 3.333	H_f n f	0.0528 0.0151 0.0283	0.0442 0.0138 0.0237	0.0376 0.0128 0.0202	0.0325 0.0119 0.0174	0.0283 0.0111 0.0152	0.0249 0.0104 0.0134	17.454 10.8930
42 3.500	H_f n f	0.0499 0.0152 0.0281	0.0418 0.0139 0.0235	0.0356 0.0128 0.0200	0.0307 0.0119 0.0173	0.0267 0.0111 0.0151	0.0236 0.0104 0.0133	19.242 12.4360
44 3.670	H_f n f	0.0473 0.0153 0.0279	0.0396 0.0140 0.0234	0.0337 0.0129 0.0199	0.0291 0.0120 0.0172	0.0254 0.0112 0.0150	0.0223 0.0105 0.0132	21.048 13.6040
48 4.000	H_f n f	0.0428 0.0154 0.0275	0.0359 0.0141 0.0230	0.0305 0.0130 0.0196	0.0263 0.0121 0.0169	0.0229 0.0113 0.0147	0.0202 0.0106 0.0130	25.132 16.2430
54 4.500	H_f n f	0.0373 0.0156 0.0270	0.0313 0.0142 0.0226	0.0266 0.0131 0.0193	0.0229 0.0122 0.0166	0.0200 0.0114 0.0145	0.0176 0.0107 0.0127	31.808 20.5580
60 5.000	H_f n f	0.0330 0.0157 0.0265	0.0277 0.0143 0.0222	0.0235 0.0132 0.0189	0.0203 0.0123 0.0163	0.0177 0.0115 0.0142	0.0156 0.0108 0.0125	39.270 25.3810
66 5.500	H_f n f	0.0294 0.0158 0.0260	0.0246 0.0144 0.0238	0.0210 0.0133 0.0185	0.0181 0.0124 0.0160	0.0158 0.0115 0.0139	0.0139 0.0108 0.0123	47.516 30.7100
72 6.000	H_f n f	0.0267 0.0159 0.0257	0.0224 0.0145 0.0215	0.0190 0.0134 0.0183	0.0164 0.0125 0.0158	0.0143 0.0116 0.0138	0.0126 0.0109 0.0121	56.548 36.5480
$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.0622$ ft.

H_f = friction loss per 100 ft.

$V = 2$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{Bmatrix}\text{in.}\\\text{ft.}\end{Bmatrix}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{Bmatrix}\text{cfs.}\\\text{mgd.}\end{Bmatrix}$
78 6.500	H_f n f	0.0241 0.0160 0.0252	0.0202 0.0146 0.0211	0.0172 0.0135 0.0180	0.0148 0.0125 0.0155	0 0129 0.0117 0.0135	0.0114 0.0110 0.0119	66.366 42.8930
84 7.000	H_f n f	0.0222 0.0161 0.0251	0.0186 0.0147 0.0210	0.0158 0.0136 0.0179	0.0137 0.0126 0.0154	0.0119 0.0118 0.0134	0.0105 0.0111 0.0118	76.970 49.7470
90 7.500	H_f n f	0.0210 0.0162 0.0248	0.0176 0.0148 0.0208	0.0150 0.0137 0.0177	0.0129 0.0127 0.0153	0.0113 0.0119 0.0133	0.0099 0.0111 0.0117	88.358 57.1070
96 8.000	H_f n f	0.0191 0.0163 0.0245	0.0160 0.0149 0.0205	0.0136 0.0138 0.0175	0.0117 0.0128 0.0151	0.0102 0.0119 0.0131	0.0090 0.0112 0.0116	100.528 64.9740
102 8.500	H_f n f	0.0177 0.0164 0.0242	0.0148 0.0150 0.0203	0.0126 0.0138 0.0173	0.0109 0.0128 0.0149	0.0095 0.0120 0.0130	0.0084 0.0112 0.0114	113.490 73.3510
108 9.000	H_f n f	0.0166 0.0165 0.0240	0.0139 0.0151 0.0201	0.0118 0.0139 0.0171	0.0102 0.0129 0.0148	0.0089 0.0120 0.0129	0.0078 0.0113 0.0113	127.234 82.2330
114 9.500	H_f n f	0.0155 0.0165 0.0237	0.0130 0.0151 0.0199	0.0111 0.0139 0.0169	0.0095 0.0129 0.0146	0.0083 0.0121 0.0127	0.0073 0.0113 0.0112	141.764 91.6240
120 10.0	H_f n f	0.0148 0.0166 0.0238	0.0124 0.0152 0.0198	0.0106 0.0140 0.0168	0.0091 0.0130 0.0145	0.0079 0.0121 0.0127	0.0070 0.0114 0.0112	157.080 101.5230
126 10.5	H_f n f	0.0137 0.0167 0.0231	0.0115 0.0152 0.0194	0.0098 0.0141 0.0165	0.0084 0.0131 0.0142	0.0073 0.0122 0.0124	0.0065 0.0114 0.0109	173.180 111.9290
132 11.000	H_f n f	0.0130 0.0167 0.0230	0.0109 0.0153 0.0193	0.0093 0.0141 0.0164	0.0080 0.0131 0.0141	0.0070 0.0122 0.0123	0.0061 0.0115 0.0108	190.066 122.8430
138 11.500	H_f n f	0.0124 0.0168 0.0229	0.0104 0.0154 0.0192	0.0088 0.0142 0.0163	0.0076 0.0132 0.0140	0.0066 0.0123 0.0122	0.0059 0.0115 0.0108	207.738 134.2640
144 12.000	H_f n f	0.0119 0.0168 0.0228	0.0100 0.0154 0.0191	0.0085 0.0142 0.0162	0.0073 0.0132 0.0140	0.0064 0.0123 0.0122	0.0056 0.0116 0.0107	226.194 146.1930
$D\begin{Bmatrix}\text{in.}\\\text{ft.}\end{Bmatrix}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{Bmatrix}\text{cfs.}\\\text{mgd.}\end{Bmatrix}$

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TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.1399$ ft.

H_f = friction loss per 100 ft.

$V = 3$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$
4 0.333	H_f n f	1.6504 0.0121 0.0393	1.3832 0.0111 0.0329	1.1761 0.0102 0.0280	1.0124 0.0095 0.0241	0.8844 0.0089 0.0211	0.7788 0.0083 0.0186	0.261 0.1686
6 0.500	H_f n f	1.0243 0.0125 0.0366	0.8582 0.0115 0.0307	0.7304 0.0106 0.0261	0.6302 0.0098 0.0225	0.5489 0.0092 0.0196	0.4833 0.0086 0.0173	0.588 0.3801
8 0.667	H_f n f	0.7305 0.0128 0.0348	0.6123 0.0117 0.0292	0.5203 0.0108 0.0248	0.4520 0.0101 0.0214	0.3913 0.0094 0.0187	0.3446 0.0088 0.0165	1.047 0.6768
10 0.833	H_f n f	0.5643 0.0131 0.0336	0.4731 0.0120 0.0282	0.4023 0.0110 0.0240	0.3471 0.0103 0.0207	0.3023 0.0096 0.0180	0.2662 0.0090 0.0159	1.635 1.0566
12 1.000	H_f n f	0.4560 0.0133 0.0326	0.3821 0.0122 0.0273	0.3251 0.0112 0.0232	0.2814 0.0104 0.0201	0.2444 0.0097 0.0175	0.2152 0.0091 0.0154	2.355 1.5222
14 1.167	H_f n f	0.3815 0.0135 0.0318	0.3190 0.0123 0.0266	0.2724 0.0114 0.0227	0.2362 0.0106 0.0196	0.2042 0.0099 0.0170	0.1798 0.0092 0.0150	3.207 2.0730
15 1.250	H_f n f	0.3510 0.0135 0.0314	0.2940 0.0124 0.0263	0.2500 0.0114 0.0224	0.2160 0.0106 0.0193	0.1881 0.0099 0.0168	0.1657 0.0093 0.0148	3.681 2.3790
16 1.333	H_f n f	0.3263 0.0136 0.0311	0.2732 0.0125 0.0261	0.2322 0.0115 0.0222	0.2014 0.0107 0.0191	0.1747 0.0100 0.0167	0.1539 0.0093 0.0147	4.188 2.7069
18 1.500	H_f n f	0.2854 0.0137 0.0306	0.2390 0.0126 0.0256	0.2031 0.0116 0.0218	0.1740 0.0108 0.0188	0.1528 0.0101 0.0164	0.1345 0.0094 0.0144	5.301 3.4260
20 1.667	H_f n f	0.2524 0.0138 0.0300	0.2113 0.0127 0.0251	0.1800 0.0117 0.0214	0.1541 0.0109 0.0184	0.1351 0.0101 0.0161	0.1189 0.0095 0.0142	6.546 4.2309
22 1.833	H_f n f	0.2262 0.0140 0.0295	0.1891 0.0128 0.0247	0.1610 0.0118 0.0210	0.1382 0.0109 0.0181	0.1211 0.0102 0.0158	0.1067 0.0096 0.0139	7.890 5.0994
24 2.000	H_f n f	0.2033 0.0141 0.0290	0.1700 0.0129 0.0243	0.1452 0.0119 0.0207	0.1252 0.0110 0.0178	0.1088 0.0103 0.0155	0.0958 0.0097 0.0137	9.426 6.0921
$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$

TABLE 1 (contd.)

$\frac{V^2}{2g} = 0.1399$ ft.

H_f = friction loss per 100 ft.

$$V = 3 \text{ fps.}$$

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$
27	H_f	0.1824	0.1532	0.1303	0.1124	0.0975	0.0859	11.928
2.250	n	0.0142	0.0130	0.0120	0.0112	0.0104	0.0098	7.7094
	f	0.0284	0.0238	0.0202	0.0174	0.0152	0.0134	
30	H_f	0.1573	0.1322	0.1122	0.0961	0.0842	0.0741	14.727
2.500	n	0.0143	0.0131	0.0121	0.0112	0.0105	0.0098	9.5184
	f	0.0280	0.0235	0.0200	0.0172	0.0150	0.0132	
33	H_f	0.1350	0.1133	0.0961	0.0830	0.0724	0.0637	17.820
2.750	n	0.0145	0.0132	0.0122	0.0113	0.0106	0.0099	11.5173
	f	0.0276	0.0231	0.0197	0.0169	0.0148	0.0130	
36	H_f	0.1264	0.1062	0.0900	0.0780	0.0675	0.0595	21.207
3.000	n	0.0146	0.0133	0.0123	0.0114	0.0107	0.0100	13.7064
	f	0.0271	0.0227	0.0193	0.0167	0.0145	0.0128	
40	H_f	0.1120	0.0942	0.0801	0.0690	0.0600	0.0529	26.181
3.333	n	0.0146	0.0134	0.0124	0.0115	0.0107	0.0101	16.3395
	f	0.0266	0.0223	0.0190	0.0164	0.0143	0.0126	
42	H_f	0.1063	0.0890	0.0762	0.0651	0.0568	0.0500	28.863
3.500	n	0.0147	0.0135	0.0125	0.0116	0.0108	0.0101	18.6546
	f	0.0264	0.0221	0.0188	0.0163	0.0142	0.0125	
44	H_f	0.1000	0.0843	0.0713	0.0622	0.0536	0.0472	31.572
3.670	n	0.0148	0.0136	0.0125	0.0116	0.0108	0.0102	20.405
	f	0.0263	0.0220	0.0187	0.0162	0.0141	0.0124	
48	H_f	0.0900	0.0751	0.0642	0.0561	0.0482	0.0425	37.698
4.000	n	0.0149	0.0136	0.0126	0.0117	0.0109	0.0102	24.365
	f	0.0257	0.0215	0.0183	0.0159	0.0138	0.0121	
54	H_f	0.0791	0.0660	0.0561	0.0490	0.0423	0.0373	47.712
4.500	n	0.0151	0.0138	0.0127	0.0118	0.0110	0.0104	30.837
	f	0.0254	0.0213	0.0181	0.0157	0.0136	0.0120	
60	H_f	0.0701	0.0590	0.0500	0.0432	0.0375	0.0330	58.905
5.000	n	0.0152	0.0139	0.0128	0.0119	0.0111	0.0104	38.071
	f	0.0249	0.0209	0.0178	0.0153	0.0133	0.0118	
66	H_f	0.0642	0.0542	0.0462	0.0390	0.0343	0.0302	71.274
5.500	n	0.0153	0.0140	0.0129	0.0120	0.0112	0.0105	46.066
	f	0.0245	0.0205	0.0175	0.0151	0.0131	0.0116	
72	H_f	0.0563	0.0473	0.0400	0.0351	0.0300	0.0264	84.822
6.000	n	0.0154	0.0141	0.0130	0.0121	0.0113	0.0106	54.822
	f	0.0242	0.0203	0.0173	0.0149	0.0130	0.0114	
$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.1399$ ft.

$V = 3$ fps.

H_f = friction loss per 100 ft.

Area A (sq.ft.) = $\dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D \begin{cases} \text{in.} \\ \text{ft.} \end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q \begin{cases} \text{cfs.} \\ \text{mgd.} \end{cases}$
78 6.500	H_f n f	0.0521 0.0155 0.0240	0.0442 0.0142 0.0201	0.0372 0.0131 0.0171	0.0322 0.0122 0.0148	0.0279 0.0114 0.0129	0.0245 0.0107 0.0113	99.549 64.340
84 7.000	H_f n f	0.0473 0.0156 0.0237	0.0390 0.0143 0.0200	0.0343 0.0132 0.0169	0.0290 0.0123 0.0145	0.0252 0.0114 0.0127	0.0222 0.0107 0.0112	115.455 74.621
90 7.500	H_f n f	0.0432 0.0157 0.0233	0.0361 0.0144 0.0195	0.0314 0.0133 0.0166	0.0271 0.0123 0.0143	0.0230 0.0115 0.0125	0.0203 0.0108 0.0110	132.537 85.661
96 8.000	H_f n f	0.0400 0.0158 0.0230	0.0342 0.0145 0.0193	0.0290 0.0133 0.0164	0.0252 0.0124 0.0142	0.0214 0.0116 0.0123	0.0189 0.0109 0.0109	150.792 97.461
102 8.500	H_f n f	0.0381 0.0159 0.0229	0.0321 0.0145 0.0192	0.0270 0.0134 0.0163	0.0231 0.0125 0.0141	0.0204 0.0116 0.0123	0.0179 0.0109 0.0108	170.235 110.026
108 9.000	H_f n f	0.0352 0.0160 0.0227	0.0290 0.0146 0.0190	0.0251 0.0135 0.0162	0.0220 0.0125 0.0139	0.0187 0.0117 0.0122	0.0165 0.0110 0.0107	190.851 123.350
114 9.500	H_f n f	0.0331 0.0160 0.0224	0.0280 0.0147 0.0188	0.0242 0.0135 0.0160	0.0201 0.0126 0.0138	0.0177 0.0117 0.0120	0.0156 0.0110 0.0106	212.646 137.437
120 10.000	H_f n f	0.0310 0.0161 0.0223	0.0262 0.0147 0.0187	0.0221 0.0136 0.0159	0.0191 0.0126 0.0137	0.0166 0.0118 0.0120	0.0146 0.0111 0.0105	235.620 152.285
126 10.500	H_f n f	0.0290 0.0161 0.0221	0.0243 0.0148 0.0185	0.0210 0.0137 0.0158	0.0183 0.0127 0.0136	0.0155 0.0118 0.0119	0.0137 0.0111 0.0104	259.770 167.894
132 11.000	H_f n f	0.0280 0.0162 0.0218	0.0231 0.0149 0.0183	0.0200 0.0137 0.0155	0.0171 0.0127 0.0134	0.0150 0.0119 0.0117	0.0132 0.0111 0.0103	285.099 184.264
138 11.500	H_f n f	0.0261 0.0163 0.0217	0.0220 0.0149 0.0182	0.0190 0.0137 0.0154	0.0163 0.0128 0.0133	0.0139 0.0119 0.0116	0.0123 0.0112 0.0102	311.607 201.397
144 12.000	H_f n f	0.0252 0.0163 0.0215	0.0210 0.0150 0.0180	0.0181 0.0138 0.0153	0.0155 0.0128 0.0133	0.0134 0.0120 0.0115	0.0118 0.0112 0.0101	339.291 219.290
$D \begin{cases} \text{in.} \\ \text{ft.} \end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q \begin{cases} \text{cfs.} \\ \text{mgd.} \end{cases}$

TABLE 1 (contd.)

$\frac{V^2}{2g} = 0.2487$ ft.

H_f = friction loss per 100 ft.

$V = 4$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$Q\begin{Bmatrix}\text{cfs.}\\\text{mgd.}\end{Bmatrix}$	$D\begin{Bmatrix}\text{in.}\\\text{ft.}\end{Bmatrix}$	$C_{\text{W}-\text{H}}$	100	110	120	130	140	150	$Q\begin{Bmatrix}\text{cfs.}\\\text{mgd.}\end{Bmatrix}$
99.549 64.340	4 0.333	H_f n f	3.1592 0.0119 0.0453	2.6474 0.0109 0.0380	2.2525 0.0100 0.0323	1.9429 0.0093 0.0279	1.6933 0.0087 0.0243	1.4911 0.0081 0.0214	0.348 0.2248
15.455 74.621	6 0.500	H_f n f	1.7309 0.0122 0.0348	1.4505 0.0112 0.0292	1.2341 0.0103 0.0248	1.0645 0.0096 0.0214	0.9277 0.0089 0.0187	0.8170 0.0084 0.0164	0.784 0.5068
32.537 85.661	8 0.667	H_f n f	1.2462 0.0126 0.0334	1.0443 0.0115 0.0280	0.8885 0.0106 0.0238	0.7664 0.0100 0.0205	0.6680 0.0092 0.0179	0.5882 0.0086 0.0158	1.396 0.9024
50.792 97.461	10 0.833	H_f n f	0.9608 0.0128 0.0322	0.8052 0.0117 0.0270	0.6851 0.0108 0.0230	0.5909 0.0100 0.0198	0.5150 0.0094 0.0173	0.4535 0.0088 0.0152	2.180 1.4088
70.235 10.026	12 1.000	H_f n f	0.7784 0.0130 0.0313	0.6523 0.0119 0.0262	0.5550 0.0110 0.0223	0.4787 0.0102 0.0192	0.4172 0.0095 0.0168	0.3674 0.0089 0.0148	3.140 2.0296
90.851 23.350	14 1.167	H_f n f	0.6481 0.0132 0.0304	0.5431 0.0120 0.0255	0.4621 0.0111 0.0217	0.3986 0.0103 0.0187	0.3474 0.0096 0.0163	0.3059 0.0090 ⊤0.0143	4.276 2.7640
12.646 37.437	15 1.250	H_f n f	0.5990 0.0132 0.0301	0.5020 0.0121 0.0252	0.4271 0.0112 0.0215	0.3684 0.0104 0.0185	0.3210 0.0097 0.0161	0.2827 0.0091 0.0142	4.908 3.1720
35.620 52.285	16 1.333	H_f n f	0.5573 0.0133 0.0298	0.4670 0.0122 0.0250	0.3974 0.0112 0.0212	0.3427 0.0104 0.0183	0.2987 0.0097 0.0160	0.2630 0.0091 0.0141	5.584 3.6092
59.770 67.894	18 1.500	H_f n f	0.4841 0.0134 0.0292	0.4057 0.0123 0.0245	0.3452 0.0114 0.0208	0.2977 0.0105 0.0180	0.2595 0.0098 0.0157	0.2285 0.0092 0.0138	7.068 4.5680
85.099 84.264	20 1.667	H_f n f	0.4267 0.0136 0.0286	0.3576 0.0124 0.0240	0.3042 0.0114 0.0204	0.2624 0.0106 0.0176	0.2287 0.0098 0.0153	0.2014 0.0093 0.0136	8.728 5.6412
11.607 01.397	22 1.833	H_f n f	0.3832 0.0137 0.0282	0.3211 0.0125 0.0236	0.2732 0.0115 0.0201	0.2357 0.0107 0.0173	0.2054 0.0100 0.0151	0.1809 0.0094 0.0133	10.520 6.7992
39.291 19.290	24 2.000	H_f n f	0.3444 0.0138 0.0278	0.2886 0.0126 0.0233	0.2456 0.0116 0.0198	0.2118 0.0108 0.0171	0.1846 0.0101 0.0149	0.1626 0.0095 0.0131	12.568 8.1228
$\begin{Bmatrix}\text{cfs.}\\\text{mgd.}\end{Bmatrix}$	$D\begin{Bmatrix}\text{in.}\\\text{ft.}\end{Bmatrix}$	$C_{\text{W}-\text{H}}$	100	110	120	130	140	150	$Q\begin{Bmatrix}\text{cfs.}\\\text{mgd.}\end{Bmatrix}$

TABLE 1 (contd.)

$\frac{V^2}{2g} = 0.2487$ ft.

H_f = friction loss per 100 ft.

$V = 4$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{cases} \text{in.} \\ \text{ft.} \end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases} \text{cfs.} \\ \text{mgd.} \end{cases}$
27	H_f	0.3039	0.2547	0.2167	0.1869	0.1629	0.1434	15.904
2.250	n	0.0139	0.0127	0.0117	0.0109	0.0102	0.0096	10.2792
	f	0.0275	0.0230	0.0196	0.0169	0.0148	0.0130	
30	H_f	0.2667	0.2235	0.1902	0.1640	0.1430	0.1259	19.636
2.500	n	0.0140	0.0128	0.0119	0.0110	0.0103	0.0096	12.6912
	f	0.0268	0.0225	0.0191	0.0165	0.0144	0.0126	
33	H_f	0.2386	0.1999	0.1701	0.1467	0.1279	0.1126	23.760
2.750	n	0.0141	0.0129	0.0119	0.0111	0.0104	0.0097	15.3564
	f	0.0264	0.0221	0.0188	0.0162	0.0142	0.0125	
36	H_f	0.2155	0.1806	0.1537	0.1325	0.1155	0.1017	28.276
3.000	n	0.0142	0.0130	0.0120	0.0112	0.0104	0.0098	18.2752
	f	0.0260	0.0218	0.0185	0.0160	0.0139	0.0123	
40	H_f	0.1910	0.1601	0.1362	0.1175	0.1024	0.0902	34.908
3.333	n	0.0144	0.0132	0.0121	0.0113	0.0105	0.0099	21.7860
	f	0.0256	0.0215	0.0183	0.0157	0.0137	0.0121	
42	H_f	0.1806	0.1513	0.1288	0.1111	0.0968	0.0852	38.484
3.500	n	0.0144	0.0132	0.0122	0.0113	0.0106	0.0099	24.8728
	f	0.0254	0.0213	0.0181	0.0156	0.0136	0.0120	
44	H_f	0.1709	0.1432	0.1219	0.1051	0.0916	0.0807	42.096
3.670	n	0.0145	0.0133	0.0122	0.0114	0.0106	0.0099	27.2072
	f	0.0252	0.0211	0.0180	0.0155	0.0135	0.0119	
48	H_f	0.1543	0.1293	0.1100	0.0949	0.0827	0.0728	50.264
4.000	n	0.0146	0.0134	0.0123	0.0114	0.0107	0.0100	32.4864
	f	0.0248	0.0208	0.0177	0.0153	0.0133	0.0117	
54	H_f	0.1349	0.1130	0.0962	0.0830	0.0723	0.0637	63.616
4.500	n	0.0148	0.0135	0.0125	0.0116	0.0108	0.0101	41.1160
	f	0.0244	0.0204	0.0174	0.0150	0.0131	0.0115	
60	H_f	0.1188	0.0996	0.0847	0.0731	0.0637	0.0561	78.540
5.000	n	0.0149	0.0136	0.0126	0.0117	0.0109	0.0102	50.7616
	f	0.0239	0.0200	0.0170	0.0147	0.0128	0.0113	
66	H_f	0.1062	0.0890	0.0757	0.0653	0.0569	0.0501	95.032
5.500	n	0.0150	0.0137	0.0127	0.0117	0.0110	0.0103	61.4208
	f	0.0235	0.0197	0.0168	0.0145	0.0126	0.0111	
72	H_f	0.0959	0.0804	0.0684	0.0590	0.0514	0.0453	113.096
6.000	n	0.0151	0.0138	0.0127	0.0118	0.0111	0.0104	73.0960
	f	0.0231	0.0194	0.0105	0.0142	0.0124	0.0109	
$D\begin{cases} \text{in.} \\ \text{ft.} \end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases} \text{cfs.} \\ \text{mgd.} \end{cases}$

TABLE 1 (contd.)

$\frac{V^2}{2g} = 0.2487$ ft.				**V = 4 fps.**			Area A (sq.ft.) $= \frac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$	
H_f = friction loss per 100 ft.							mgd. $\times$ 694.4 (700) = gpm.	

$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$
78 6.500	H_f	0.0869	0.0728	0.0620	0.0534	0.0466	0.0410	132.732
	n	0.0152	0.0139	0.0128	0.0119	0.0111	0.0104	85.7868
	f	0.0227	0.0190	0.0162	0.0140	0.0122	0.0107	
84 7.000	H_f	0.0800	0.0670	0.0570	0.0492	0.0429	0.0378	153.940
	n	0.0153	0.0140	0.0129	0.0120	0.0112	0.0105	99.4940
	f	0.0226	0.0189	0.0161	0.0139	0.0121	0.0106	
90 7.500	H_f	0.0740	0.0620	0.0528	0.0455	0.0397	0.0349	176.716
	n	0.0154	0.0141	0.0130	0.0121	0.0113	0.0106	114.2144
	f	0.0223	0.0187	0.0159	0.0137	0.0119	0.0105	
96 8.000	H_f	0.0691	0.0579	0.0493	0.0425	0.0370	0.0326	201.056
	n	0.0155	0.0142	0.0131	0.0121	0.0113	0.0106	129.9484
	f	0.0221	0.0185	0.0158	0.0136	0.0118	0.0104	
102 8.500	H_f	0.0638	0.0535	0.0455	0.0392	0.0342	0.0301	226.980
	n	0.0156	0.0142	0.0131	0.0122	0.0114	0.0107	146.7012
	f	0.0218	0.0183	0.0155	0.0134	0.0117	0.0103	
108 9.000	H_f	0.0599	0.0502	0.0427	0.0368	0.0321	0.0283	254.468
	n	0.0156	0.0143	0.0132	0.0123	0.0114	0.0107	164.4668
	f	0.0217	0.0182	0.0154	0.0133	0.0116	0.0102	
114 9.500	H_f	0.0560	0.0469	0.0399	0.0344	0.0300	0.0265	283.528
	n	0.0157	0.0144	0.0132	0.0123	0.0115	0.0108	183.2488
	f	0.0216	0.0181	0.0154	0.0133	0.0116	0.0101	
120 10.000	H_f	0.0534	0.0448	0.0381	0.0328	0.0286	0.0252	314.160
	n	0.0158	0.0144	0.0133	0.0124	0.0115	0.0108	203.047
	f	0.0215	0.0180	0.0153	0.0132	0.0115	0.0101	
126 10.500	H_f	0.0495	0.0415	0.0353	0.0304	0.0265	0.0233	346.360
	n	0.0158	0.0145	0.0134	0.0124	0.0116	0.0109	223.8584
	f	0.0210	0.0176	0.0151	0.0130	0.0114	0.0099	
132 11.000	H_f	0.0469	0.0393	0.0334	0.0288	0.0251	0.0221	380.132
	n	0.0159	0.0145	0.0134	0.0124	0.0116	0.0109	245.6856
	f	0.0207	0.0173	0.0148	0.0128	0.0112	0.0098	
138 11.500	H_f	0.0436	0.0365	0.0311	0.0268	0.0234	0.0206	415.476
	n	0.0159	0.0146	0.0135	0.0125	0.0117	0.0109	268.5292
	f	0.0202	0.0169	0.0144	0.0125	0.0109	0.0095	
144 12.000	H_f	0.0430	0.0360	0.0307	0.0264	0.0230	0.0203	452.388
	n	0.0160	0.0146	0.0135	0.0125	0.0117	0.0110	292.3860
	f	0.0200	0.0168	0.0143	0.0123	0.0107	0.0094	
$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	$C_{\text{W-H}}$	**100**	**110**	**120**	**130**	**140**	**150**	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.3887$ ft.

H_f = friction loss per 100 ft.

$V = 5$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{Bmatrix}\text{in.}\\\text{ft.}\end{Bmatrix}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{Bmatrix}\text{cfs.}\\\text{mgd.}\end{Bmatrix}$
4 0.3333	H_f	4.2213	3.5374	3.0098	2.5961	2.2626	1.9925	0.435
	n	0.0117	0.0107	0.0099	0.0092	0.0086	0.0080	0.281
	f	0.0362	0.0303	0.0258	0.0223	0.0194	0.0171	
6 0.5000	H_f	2.6354	2.2084	1.8790	1.6208	1.4126	1.2439	0.980
	n	0.0121	0.0110	0.0102	0.0095	0.0088	0.0083	0.634
	f	0.0339	0.0284	0.0242	0.0208	0.0182	0.0160	
8 0.6667	H_f	1.8831	1.5780	1.3427	1.1581	1.0093	0.8888	1.745
	n	0.0124	0.0113	0.0104	0.0097	0.0091	0.0085	1.128
	f	0.0323	0.0271	0.0230	0.0199	0.0173	0.0152	
10 0.8333	H_f	1.4552	1.2195	1.0376	0.8949	0.7800	0.6868	2.725
	n	0.0126	0.0115	0.0106	0.0099	0.0092	0.0087	1.761
	f	0.0312	0.0261	0.0222	0.0192	0.0167	0.0147	
12 1.0000	H_f	1.1738	0.9836	0.8369	0.7219	0.6292	0.5540	3.925
	n	0.0128	0.0117	0.0108	0.0100	0.0094	0.0088	2.537
	f	0.0302	0.0253	0.0215	0.0186	0.0162	0.0143	
14 1.1667	H_f	0.9863	0.8265	0.7032	0.6066	0.5287	0.4655	5.345
	n	0.0130	0.0119	0.0110	0.0102	0.0095	0.0089	3.455
	f	0.0296	0.0248	0.0211	0.0182	0.0159	0.0140	
15 1.250	H_f	0.9050	0.7584	0.6453	0.5566	0.4851	0.4272	6.135
	n	0.0130	0.0119	0.0110	0.0102	0.0095	0.0089	3.965
	f	0.0291	0.0244	0.0207	0.0179	0.0156	0.0137	
16 1.3333	H_f	0.8418	0.7054	0.6002	0.5177	0.4512	0.3973	6.980
	n	0.0131	0.0120	0.0111	0.0103	0.0096	0.0090	4.512
	f	0.0288	0.0241	0.0205	0.0177	0.0154	0.0136	
18 1.5000	H_f	0.7307	0.6123	0.5210	0.4494	0.3917	0.3449	8.835
	n	0.0132	0.0121	0.0112	0.0104	0.0097	0.0091	5.710
	f	0.0282	0.0236	0.0201	0.0173	0.0151	0.0133	
20 1.6667	H_f	0.6459	0.5413	0.4605	0.3972	0.3462	0.3049	10.910
	n	0.0133	0.0122	0.0113	0.0105	0.0098	0.0092	7.052
	f	0.0277	0.0232	0.0198	0.0170	0.0148	0.0131	
22 1.8333	H_f	0.5799	0.4859	0.4135	0.3566	0.3108	0.2737	13.150
	n	0.0135	0.0123	0.0114	0.0106	0.0099	0.0092	8.499
	f	0.0273	0.0229	0.0195	0.0168	0.0146	0.0129	
24 2.0000	H_f	0.5227	0.4380	0.3727	0.3215	0.2802	0.2467	15.710
	n	0.0136	0.0124	0.0115	0.0106	0.0099	0.0093	10.154
	f	0.0269	0.0225	0.0192	0.0165	0.0144	0.0127	
$D\begin{Bmatrix}\text{in.}\\\text{ft.}\end{Bmatrix}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{Bmatrix}\text{cfs.}\\\text{mgd.}\end{Bmatrix}$

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.3887$ ft.

H_f = friction loss per 100 ft.

$V = 5$ fps.

Area A (sq.ft.) = $\dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$
27 2.250	H_f n f	0.4577 0.0137 0.0265	0.3836 0.0125 0.0222	0.3263 0.0116 0.0189	0.2815 0.0107 0.0163	0.2453 0.0100 0.0142	0.2160 0.0094 0.0125	19.880 12.849
30 2.500	H_f n f	0.4027 0.0138 0.0259	0.3375 0.0126 0.0217	0.2871 0.0117 0.0185	0.2477 0.0108 0.0159	0.2158 0.0101 0.0139	0.1901 0.0095 0.0122	24.545 15.864
33 2.750	H_f n f	0.3603 0.0139 0.0255	0.3019 0.0127 0.0214	0.2569 0.0118 0.0182	0.2216 0.0109 0.0157	0.1931 0.0102 0.0137	0.1701 0.0096 0.0120	29.700 19.196
36 3.000	H_f n f	0.3253 0.0140 0.0251	0.2726 0.0128 0.0210	0.2319 0.0118 0.0179	0.2001 0.0110 0.0154	0.1744 0.0103 0.0135	0.1535 0.0096 0.0118	35.345 22.844
40 3.333	H_f n f	0.2880 0.0141 0.0247	0.2413 0.0129 0.0207	0.2053 0.0119 0.0176	0.1771 0.0111 0.0152	0.1544 0.0104 0.0132	0.1359 0.0097 0.0117	43.635 27.233
42 3.500	H_f n f	0.2722 0.0142 0.0245	0.2281 0.0130 0.0205	0.1941 0.0120 0.0175	0.1674 0.0111 0.0151	0.1459 0.0104 0.0131	0.1285 0.0098 0.0116	48.105 31.091
44 3.670	H_f n f	0.2573 0.0143 0.0243	0.2156 0.0131 0.0204	0.1835 0.0120 0.0173	0.1582 0.0112 0.0149	0.1379 0.0104 0.0130	0.1214 0.0098 0.0115	52.620 34.009
48 4.000	H_f n f	0.2332 0.0144 0.0240	0.1954 0.0131 0.0201	0.1663 0.0121 0.0171	0.1434 0.0113 0.0148	0.1250 0.0105 0.0129	0.1101 0.0099 0.0113	62.830 40.608
54 4.500	H_f n f	0.2039 0.0145 0.0236	0.1709 0.0133 0.0198	0.1454 0.0123 0.0168	0.1254 0.0114 0.0145	0.1093 0.0106 0.0126	0.0962 0.0100 0.0111	79.520 51.395
60 5.000	H_f n f	0.1795 0.0146 0.0231	0.1504 0.0134 0.0194	0.1280 0.0124 0.0165	0.1104 0.0115 0.0142	0.0962 0.0107 0.0124	0.0847 0.0101 0.0109	98.175 63.452
66 5.500	H_f n f	0.1605 0.0147 0.0227	0.1345 0.0135 0.0190	0.1144 0.0125 0.0162	0.0987 0.0116 0.0140	0.0860 0.0108 0.0122	0.0758 0.0101 0.0107	118.790 76.776
72 6.000	H_f n f	0.1452 0.0148 0.0224	0.1217 0.0136 0.0188	0.1035 0.0125 0.0160	0.0893 0.0116 0.0138	0.0778 0.0109 0.0120	0.0685 0.0102 0.0106	141.370 91.370
$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$

(cfs.)
(fps.)
gpm.

cfs.
mgd.

435
281

980
634

745
128

725
761

925
537

345
455

135
965

980
512

835
710

910
052

150
499

710
154

cfs.
mgd.

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.3887$ ft.

H_f = friction loss per 100 ft.

V = 5 fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$
78	H_f	0.1316	0.1103	0.0938	0.0809	0.0705	0.0621	165.915
6.500	n	0.0149	0.0137	0.0126	0.0117	0.0109	0.0103	107.233
	f	0.0220	0.0184	0.0157	0.0136	0.0118	0.0104	
84	H_f	0.1213	0.1016	0.0865	0.0746	0.0650	0.0573	192.425
7.000	n	0.0150	0.0138	0.0127	0.0118	0.0110	0.0103	124.368
	f	0.0219	0.0184	0.0156	0.0135	0.0117	0.0103	
90	H_f	0.1119	0.0938	0.0798	0.0688	0.0600	0.0528	220.895
7.500	n	0.0151	0.0138	0.0128	0.0119	0.0111	0.0104	142.768
	f	0.0216	0.0181	0.0154	0.0133	0.0116	0.0102	
96	H_f	0.1039	0.0871	0.0741	0.0639	0.0557	0.0490	251.320
8.000	n	0.0152	0.0139	0.0129	0.0119	0.0112	0.0105	162.436
	f	0.0214	0.0179	0.0152	0.0131	0.0115	0.0101	
102	H_f	0.0969	0.0812	0.0691	0.0596	0.0519	0.0457	283.725
8.500	n	0.0153	0.0140	0.0129	0.0120	0.0112	0.0105	183.377
	f	0.0212	0.0178	0.0151	0.0130	0.0114	0.0100	
108	H_f	0.0907	0.0760	0.0647	0.0558	0.0486	0.0428	318.085
9.000	n	0.0154	0.0141	0.0130	0.0121	0.0113	0.0106	205.584
	f	0.0210	0.0176	0.0150	0.0129	0.0113	0.0099	
114	H_f	0.0850	0.0712	0.0606	0.0523	0.0456	0.0401	254.410
9.500	n	0.0154	0.0141	0.0130	0.0121	0.0113	0.0106	229.061
	f	0.0208	0.0174	0.0148	0.0128	0.0112	0.0098	
120	H_f	0.0801	0.0671	0.0571	0.0493	0.0429	0.0378	392.700
10.000	n	0.0155	0.0142	0.0131	0.0122	0.0113	0.0106	253.809
	f	0.0206	0.0173	0.0147	0.0127	0.0110	0.0097	
126	H_f	0.0756	0.0634	0.0539	0.0465	0.0405	0.0357	432.950
10.500	n	0.0156	0.0142	0.0131	0.0122	0.0114	0.0107	279.823
	f	0.0204	0.0172	0.0146	0.0126	0.0109	0.0096	
132	H_f	0.0712	0.0597	0.0508	0.0438	0.0382	0.0336	475.165
11.000	n	0.0156	0.0143	0.0132	0.0122	0.0114	0.0107	307.107
	f	0.0202	0.0169	0.0144	0.0125	0.0108	0.0095	
138	H_f	0.0680	0.0570	0.0485	0.0418	0.0364	0.0321	319.345
11.500	n	0.0157	0.0144	0.0132	0.0123	0.0115	0.0108	335.662
	f	0.0201	0.0169	0.0143	0.0124	0.0107	0.0094	
144	H_f	0.0647	0.0542	0.0461	0.0398	0.0347	0.0305	565.485
12.000	n	0.0157	0.0144	0.0133	0.0123	0.0115	0.0108	365.483
	f	0.0200	0.0168	0.0142	0.0123	0.0106	0.0093	
$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.5597$ ft.

H_f = friction loss per 100 ft.

$V = 6$ fps.

Area A (sq.ft.) $= \dfrac{Q \ (\text{cfs.})}{V \ (\text{fps.})}$

mgd. $\times$ 694.4 (700) = gpm.

$Q\begin{cases}\text{cfs.}\\ \text{mgd.}\end{cases}$	$D\begin{cases}\text{in.}\\ \text{ft.}\end{cases}$	$C_{\text{W−H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\ \text{mgd.}\end{cases}$
65.915	4	H_f	5.9440	4.9811	4.2381	3.6556	3.1860	2.8056	0.522
07.233	0.333	n	0.0115	0.0106	0.0097	0.0090	0.0084	0.0079	0.337
		f	0.0354	0.0297	0.0252	0.0218	0.0190	0.0167	
92.425	6	H_f	3.7052	3.1050	2.6418	2.2787	1.9860	1.7489	1.176
24.368	0.500	n	0.0119	0.0109	0.0101	0.0094	0.0087	0.0082	0.760
		f	0.0331	0.0277	0.0236	0.0204	0.0177	0.0156	
20.895	8	H_f	2.6447	2.2163	1.8857	1.6265	1.4176	1.2483	2.094
42.768	0.667	n	0.0122	0.0112	0.0103	0.0096	0.0089	0.0084	1.354
		f	0.0315	0.0264	0.0225	0.0194	0.0169	0.0149	
51.320	10	H_f	2.0618	1.7278	1.4701	1.2680	1.1051	0.9732	3.270
62.436	0.833	n	0.0124	0.0114	0.0105	0.0098	0.0091	0.0085	2.113
		f	0.0307	0.0257	0.0219	0.0189	0.0165	0.0145	
83.725	12	H_f	1.6511	1.3836	1.1772	1.0154	0.8850	0.7793	4.710
83.377	1.000	n	0.0126	0.0116	0.0107	0.0099	0.0092	0.0087	3.044
		f	0.0295	0.0247	0.0210	0.0181	0.0158	0.0139	
18.085	14	H_f	1.3767	1.1537	0.9816	0.8467	0.7379	0.6498	6.414
05.584	1.167	n	0.0128	0.0117	0.0108	0.0100	0.0094	0.0088	4.146
		f	0.0287	0.0241	0.0205	0.0177	0.0154	0.0135	
54.410	15	H_f	1.2715	1.0655	0.9066	0.7820	0.6815	0.6000	7.362
29.061	1.250	n	0.0129	0.0118	0.0109	0.0101	0.0094	0.0088	4.758
		f	0.0284	0.0238	0.0202	0.0175	0.0152	0.0134	
92.700	16	H_f	1.1824	0.9909	0.8431	0.7272	0.6338	0.5581	8.376
53.809	1.333	n	0.0129	0.0119	0.0109	0.0101	0.0095	0.0089	5.414
		f	0.0281	0.0235	0.0200	0.0173	0.0151	0.0133	
32.950	18	H_f	1.0300	0.8631	0.7344	0.6335	0.5521	0.4862	10.602
79.823	1.500	n	0.0130	0.0120	0.0110	0.0102	0.0096	0.0090	6.852
		f	0.0276	0.0231	0.0197	0.0170	0.0148	0.0130	
75.165	20	H_f	0.9067	0.7598	0.6465	0.5576	0.4860	0.4280	13.092
07.107	1.667	n	0.0132	0.0121	0.0111	0.0103	0.0097	0.0090	8.462
		f	0.0270	0.0226	0.0193	0.0166	0.0145	0.0127	
9.345	22	H_f	0.8134	0.6816	0.5800	0.5002	0.4360	0.3839	15.780
35.662	1.833	n	0.0133	0.0122	0.0112	0.0104	0.0098	0.0091	10.199
		f	0.0266	0.0223	0.0190	0.0163	0.0143	0.0126	
55.485	24	H_f	0.7359	0.6167	0.5247	0.4526	0.3944	0.3473	18.852
55.483	2.000	n	0.0134	0.0123	0.0113	0.0105	0.0099	0.0092	12.184
		f	0.0263	0.0220	0.0188	0.0162	0.0141	0.0124	
$\begin{cases}\text{cfs.}\\ \text{mgd.}\end{cases}$	$D\begin{cases}\text{in.}\\ \text{ft.}\end{cases}$	$C_{\text{W−H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\ \text{mgd.}\end{cases}$

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.5597$ ft.

H_f = friction loss per 100 ft.

$V = 6$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.}}{V \text{ (fps.}}$

mgd. $\times$ 694.4 (700) = gpm.

$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$	$D\begin{cases}\text{i}\\\end{cases}$
27 2.250	H_f n f	0.6441 0.0135 0.0259	0.5398 0.0124 0.0217	0.4592 0.0114 0.0185	0.3961 0.0106 0.0159	0.3452 0.0099 0.0139	0.3040 0.0093 0.0122	23.856 15.419	78 6.5
30 2.500	H_f n f	0.5665 0.0136 0.0253	0.4747 0.0125 0.0212	0.4039 0.0115 0.0180	0.3484 0.0107 0.0156	0.3036 0.0100 0.0135	0.2674 0.0094 0.0119	29.454 19.037	84 7.0
33 2.750	H_f n f	0.5067 0.0137 0.0249	0.4245 0.0126 0.0209	0.3613 0.0116 0.0178	0.3116 0.0108 0.0153	0.2716 0.0101 0.0133	0.2392 0.0094 0.0118	35.640 23.035	90 7.5
36 3.000	H_f n f	0.4569 0.0138 0.0245	0.3829 0.0127 0.0205	0.3258 0.0117 0.0175	0.2810 0.0109 0.0151	0.2449 0.0101 0.0131	0.2157 0.0095 0.0116	42.414 27.413	9 8.0
40 3.333	H_f n f	0.4046 0.0139 0.0241	0.3391 0.0128 0.0202	0.2885 0.0118 0.0172	0.2488 0.0109 0.0148	0.2169 0.0102 0.0129	0.1910 0.0196 0.0114	52.362 32.679	10 8.5
42 3.500	H_f n f	0.3822 0.0140 0.0239	0.3203 0.0129 0.0200	0.2725 0.0119 0.0170	0.2351 0.0110 0.0147	0.2049 0.0103 0.0128	0.1804 0.0097 0.0113	57.726 37.309	10 9.0
44 3.670	H_f n f	0.3614 0.0141 0.0237	0.3029 0.0129 0.0199	0.2577 0.0119 0.0169	0.2223 0.0110 0.0146	0.1937 0.0103 0.0127	0.1706 0.0097 0.0112	63.144 40.811	11 9.5
48 4.000	H_f n f	0.3274 0.0142 0.0234	0.2744 0.0130 0.0196	0.2334 0.0120 0.0167	0.2014 0.0111 0.0144	0.1755 0.0104 0.0125	0.1545 0.0097 0.0111	75.396 48.730	12 10.
54 4.500	H_f n f	0.2861 0.0143 0.0230	0.2398 0.0131 0.0193	0.2040 0.0121 0.0164	0.1760 0.0112 0.0142	0.1533 0.0105 0.0123	0.1350 0.0098 0.0109	95.424 61.674	1 10.
60 5.000	H_f n f	0.2518 0.0145 0.0225	0.2110 0.0132 0.0189	0.1795 0.0122 0.0160	0.1549 0.0113 0.0138	0.1350 0.0106 0.0121	0.1188 0.0099 0.0106	117.810 76.142	1 11.
66 5.500	H_f n f	0.2250 0 0146 0.0221	0.1886 0 0133 0.0185	0.1604 0.0123 0.0158	0.1384 0.0114 0.0136	0.1206 0.0107 0.0118	0.1062 0.0100 0.0104	142.548 92.131	1 11.
72 6.000	H_f n f	0.2034 0.2147 0.0218	0.1704 0.0134 0.0183	0.1450 0.0124 0.0155	0.1251 0.0115 0.0134	0.1090 0.0107 0.0117	0.0960 0.0101 0.0103	169.644 109.644	1 12.
$D\begin{cases}\text{in.}\\\text{ft.}\end{cases}$	C_{W-H}	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\\text{mgd.}\end{cases}$	D

TABLE 1 (contd.)

$\dfrac{V^2}{2g} = 0.5597$ ft.

H_f = friction loss per 100 ft.

$V = 6$ fps.

Area A (sq.ft.) $= \dfrac{Q \text{ (cfs.)}}{V \text{ (fps.)}}$

mgd. $\times$ 694.4 (700) = gpm.

$Q\begin{cases}\text{cfs.}\\ \text{mgd}\end{cases}$	$D\begin{cases}\text{in.}\\ \text{ft.}\end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\ \text{mgd.}\end{cases}$
23.856	78	H_f	0.1842	0.1544	0.1313	0.1133	0.0987	0.0869	199.098
15.419	6.500	n	0.0148	0.0135	0.0125	0.0116	0.0108	0.0101	128.680
		f	0.0214	0.0179	0.0153	0.0132	0.0115	0.0101	
29.454	84	H_f	0.1700	0.1425	0.1212	0.1046	0.0911	0.0802	230.910
19.037	7.000	n	0.0149	0.0136	0.0126	0.0117	0.0109	0.0102	149.241
		f	0.0213	0.0178	0.0152	0.0131	0.0114	0.0101	
35.640	90	H_f	0.1574	0.1319	0.1122	0.0968	0.0844	0.0743	265.074
23.035	7.500	n	0.0149	0.0137	0.0126	0.0117	0.0109	0.0103	171.322
		f	0.0211	0.0177	0.0150	0.0130	0.0113	0.0100	
42.414	96	H_f	0.1463	0.1226	0.1043	0.0900	0.0784	0.0691	301.584
27.413	8.000	n	0.0150	0.0138	0.0127	0.0118	0.0110	0.0103	194.923
		f	0.0209	0.0175	0.0149	0.0129	0.0112	0.0099	
52.362	102	H_f	0.1360	0.1140	0.0970	0.0836	0.0729	0.0642	340.470
32.679	8.500	n	0.0151	0.0138	0.0128	0.0118	0.0111	0.0104	220.052
		f	0.0207	0.0173	0.0148	0.0127	0.0111	0.0098	
57.726	108	H_f	0.1271	0.1065	0.0906	0.0782	0.0681	0.0600	381.702
37.309	9.000	n	0.0152	0.0139	0.0128	0.0119	0.0111	0.0104	246.700
		f	0.0204	0.0171	0.0146	0.0125	0.0109	0.0096	
63.144	114	H_f	0.1191	0.0998	0.0849	0.0732	0.0638	0.0562	425.292
40.811	9.500	n	0.0152	0.0139	0.0129	0.0120	0.0112	0.0105	274.873
		f	0.0202	0.0169	0.0144	0.0124	0.0108	0.0095	
75.396	120	H_f	0.1122	0.0940	0.0800	0.0690	0.0601	0.0530	471.240
48.730	10.000	n	0.0153	0.0140	0.0129	0.0120	0.0112	0.0105	304.570
		f	0.0200	0.0168	0.0143	0.0123	0.0107	0.0094	
95.424	126	H_f	0.1073	0.0899	0.0765	0.0659	0.0575	0.0506	519.540
61.674	10.500	n	0.0154	0.0141	0.0130	0.0121	0.0113	0.0106	335.788
		f	0.0199	0.0167	0.0142	0.0122	0.0106	0.0094	
17.810	132	H_f	0.1004	0.0841	0.0716	0.0617	0.0538	0.0474	570.199
76.142	11.000	n	0.0154	0.0141	0.0130	0.0121	0.0113	0.0106	368.528
		f	0.0197	0.0165	0.0140	0.0121	0.0106	0.0093	
42.548	138	H_f	0.0956	0.0801	0.0682	0.0588	0.0512	0.0451	623.214
92.131	11.500	n	0.0155	0.0142	0.0131	0.0121	0.0113	0.0106	402.794
		f	0.0195	0.0163	0.0139	0.0120	0.0105	0.0092	
59.644	144	H_f	0.0908	0.0761	0.0647	0.0558	0.0487	0.0428	678.582
09.644	12.000	n	0.0155	0.0142	0.0131	0.0122	0.0114	0.0107	438.579
		f	0.0194	0.0163	0.0138	0.0119	0.0104	0.0091	
$\begin{cases}\text{cfs.}\\ \text{mgd.}\end{cases}$	$D\begin{cases}\text{in.}\\ \text{ft.}\end{cases}$	$C_{\text{W-H}}$	100	110	120	130	140	150	$Q\begin{cases}\text{cfs.}\\ \text{mgd.}\end{cases}$

TABLE 2

Multiplying Factors K* Corresponding to Various Values of Williams-Hazen C and Darcy f

C	K	C	K	C	K	C	K
40	5.457	70	1.936	100†	1.000	130	0.615
41	5.213	71	1.886	101	0.982	131	0.606
42	4.986	72	1.837	102	0.964	132	0.598
43	4.773	73	1.791	103	0.947	133	0.590
44	4.574	74	1.747	104	0.930	134	0.582
45	4.388	75	1.704	105	0.914	135	0.574
46	4.213	76	1.662	106	0.898	136	0.566
47	4.048	77	1.623	107	0.882	137	0.558
48	3.893	78	1.584	108	0.867	138	0.551
49	3.748	79	1.547	109	0.852	139	0.543
50	3.610	80	1.512	110	0.838	140	0.536
51	3.480	81	1.477	111	0.824	141	0.529
52	3.370	82	1.444	112	0.811	142	0.522
53	3.241	83	1.412	113	0.797	143	0.516
54	3.131	84	1.381	114	0.785	144	0.509
55	3.026	85	1.351	115	0.772	145	0.503
56	2.927	86	1.322	116	0.760	146	0.496
57	2.832	87	1.294	117	0.748	147	0.490
58	2.742	88	1.267	118	0.736	148	0.484
59	2.657	89	1.241	119	0.725	149	0.478
60	2.576	90	1.215	120	0.713	150	0.472
61	2.498	91	1.191	121	0.703	151	0.466
62	2.424	92	1.167	122	0.692	152	0.461
63	2.353˙	93	1.144	123	0.682	153	0.455
64	2.285	94	1.121	124	0.671	154	0.449
65	2.221	95	1.100	125	0.661	155	0.444
66	2.159	96	1.079	126	0.652	156	0.439
67	2.099	97	1.058	127	0.642	157	0.434
68	2.043	98	1.038	128	0.633	158	0.429
69	1.988	99	1.019	129	0.624	159	0.424

* These values of "K" are the ratio of $C^{1.852}$ to $C'^{1.852}$ where $C = 100$. They are to be applied to H_f (friction head loss per 100 ft. of pipe) and to values of "f" in the Darcy formula. For example, the value of $C^{1.852}$ when $C = 100$ is 5,058.3. The value of $C'^{1.852}$ when $C' = 130$ is 8,223. Then $\dfrac{C^{1.852}}{C'^{1.852}} = \dfrac{5,058.3}{8,225} = 0.615$. In the Williams-Hazen formula, when the C of a 48-in. pipe equals 100, $H_f = 0.090$ when $V = 3$ fps. Then $0.090 \times 0.615 = 0.0553$, which is the friction head loss per 100 ft. of 48-in. pipe at a velocity of 3 fps. when $C' = 130$. Also, the factors apply to the values of "f" in the Darcy formula (Eq. 3). For a 48-in. pipe and at a velocity of 3 fps. "f" = .0257. Then .0257 × .615 = .0158 which is the value of "f" for a 48-in. pipe when $V = 3$ fps. and when $C = 130$.

These factors "K" may also be used to tie in the Williams-Hazen formula with the R-f formulas to make f dimensionless. For example, in Fig. 2, for a 6-in. pipe at a ve-

locity of 3 fps., the Reynolds number R, when the kinematic viscosity of water at 50°F. is 0.0000141, is 17,000. This R line intersects the "smooth" line at a point corresponding to $f = 0.02$. In Table 1, the value of f when $C = 100$ is given as 0.0366 for a 6-in. pipe at a velocity of 3 fps This 0.02 divided by 0.0366 = 0.546, which is the K factor for $C = 139$. Again where the R line in Fig. 2 crosses $\dfrac{r}{k} = 10$, the corresponding f is 0.07. This r is the radius of the pipe in inches. Then $\dfrac{3}{k} = 10$, or $10k = 3$, or $k = 0.3$ in. Now when $C = 100$, $f = 0.0366$ for a velocity of 3 fps. in 6-in. pipe. Then $\dfrac{0.07}{0.0366}$ = 1.9 and, in Table 2, $K = 1.9$ corresponds to $C = 71$. Therefore the "average" height of the tubercles is 0.3 in. for $C = 71$ when $f = 0.07$ in a 6-in. pipe when the velocity is 3 fps.

† Base.

(left margin, partial column)

Darcy f

K
0.615
0.606
0.598
0.590
0.582
0.574
0.566
0.558
0.551
0.543
0.536
0.529
0.522
0.516
0.509
0.503
0.496
0.490
0.484
0.478
0.472
0.466
0.461
0.455
0.449
0.444
0.439
0.434
0.429
0.424

per R, ter at R line corre- value for a s 0.02 the K R line

ding f ipe in = 0.3 for a 0.07 0.0366 ponds height when ity is

fluids. The **R** parameter is important because it uses a rational approach and provides a competent standard by which all purely empirical formulas may be measured.

In the flow of water through pipelines, there are two critical velocities: the velocity below which streamline flow exists, and the velocity above which turbulent flow exists. At 50°F.,

Until recently the impression was that friction head loss was due to the flow of water immediately adjacent to the wall of the pipe. Later experiments indicate that there is no velocity at the wall of the pipe. The friction is due to the water molecules sliding past one another, and this friction is increased by the eddy flow of the water near the pipe surface.
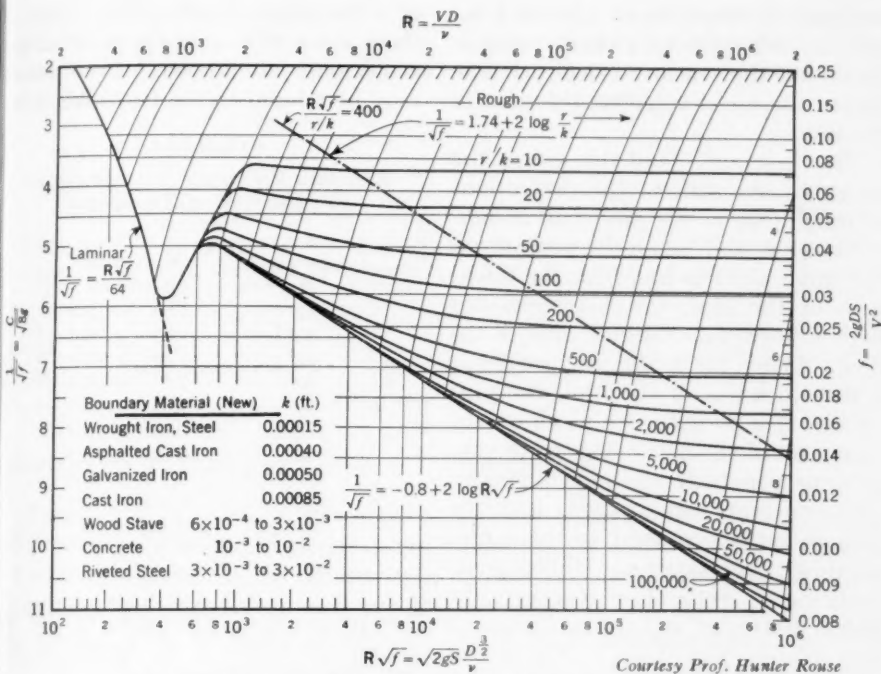
Fig. 2. Proposed Resistance Diagram for Commercial Pipe

Reynolds' earlier experiments gave the lower critical velocity as 0.69 fps. for $\frac{1}{2}$-in. pipe and 0.029 fps. for 12-in. pipe. The higher critical velocity was 4.34 fps. for $\frac{1}{2}$-in. pipe and 0.181 fps. for 12-in. pipe. Therefore, in small size pipe, there may be streamline flow at very high velocities; but streamline flow takes place only at very low velocities in large pipe.

The energy lost by friction is dissipated as heat and is the cause of a drop in pressure in a pipeline when water flows through it. Whether a liquid has a streamline flow or an eddy flow depends upon the viscosity of the fluid; and this, in turn, depends upon its temperature. Also, experiments indicate that "critical velocity" is not a definite velocity but a region

of transition from streamline or viscous flow to turbulent or eddy flow.

When we speak of the "velocity" of water we mean the "mean" velocity of the water; this is zero at the immediate surface of the pipe and increases to its maximum at the center. For very smooth pipe there is a film of water at the surface called the "laminar film." In rougher pipe, eddy currents are caused. This film amounts to from about $\frac{1}{200}$ to $\frac{1}{6}$ in. and depends primarily on the magnitude of the mean velocity. The higher the mean velocity, the thinner the film.

The "average" (and this means the weighted average) of the projections of roughness on the pipe wall is indicated by k, and, when the projections are small and k is less than the thickness of the film, the roughness has little influence on the character of the flow. When the projections are about $\frac{1}{4}$ the thickness of the film, the pipe surface has no influence at all on the character of the flow. When the projections penetrate the film, however, eddy currents are caused, and the flow becomes turbulent to the extent of these penetrations. If the penetrations are very close together, the film is destroyed, and the flow becomes "completely turbulent." The Reynolds number is inapplicable to completely turbulent flow. In long transmission pipelines, where the flow is uniform and the mean velocity is relatively low, the flow may not reach the completely turbulent stage at all, and roughness, beyond a certain stage, need not be considered.

When the projections are large, however, f, as a dimensionless function, provides a means of measuring the value of k. This is very valuable even in completely turbulent flows. It is for this reason that, in the turbu-

lent area of Fig. 2, provided by Prof. Hunter Rouse (1), the lines which represent different degrees of the value of r/k are horizontal, and, where the curves strike these lines, relative values of f may be determined. relative values of f are known in terms of any formula for which the corresponding values of different coefficients are known, one of them may be taken as a base to find the value of f for other coefficients. Also, the values of f in terms of arbitrary coefficients are known, those values may be related to the Reynolds number parameter. Examples of this are given in Table 2 in terms of the Williams-Hazen formula.

In water distribution systems the water may be turbulent for other reasons than the roughness of the pipe walls, such as: inlets and outlets rough joints, surge flows and so on Uniform flows are therefore important in using the Reynolds parameter to determine pipe wall conditions in all pipelines. In water distribution systems, except in the small hours of the morning, the water is always apt to be turbulent. Generally the temperature will be found to be close to

TABLE 3

Kinematic Viscosity of Water for Normal Temperatures at Atmospheric Pressure

Temperature °F.	Kinematic Viscosity
32°	1.93×10^{-5}
40°	1.67×10^{-5}
50°	1.41×10^{-5}
60°	1.21×10^{-5}
70°	1.05×10^{-5}
80°	0.930×10^{-5}
90°	0.823×10^{-5}
100°	0.736×10^{-5}
120°	0.610×10^{-5}
150°	0.476×10^{-5}
180°	0.385×10^{-5}
212°	0.319×10^{-5}

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50°F., and the kinematic viscosity of the water will be close to 0.0000141. The kinematic viscosities of water at atmospheric pressure for temperatures apt to be encountered are given in Table 3.

Water is not a very viscous fluid. The difference in temperature and therefore kinematic viscosity does not have a great effect on the flow, but it should never be neglected in making tests. Tables 4 and 5 present data collected by Julian Hinds (2) which show the relation of different values of f to R.

ciliation can be found for the Fanning and the Williams-Hazen formulas. The Williams-Hazen formula and the R formulas cannot be completely reconciled for the entire range between 4-in. and 96-in. pipe, but above 18-in. a very close reconciliation is found. For pipe from 4 to 18 in. in diameter, a close reconciliation is found in terms of the next higher values of f in terms of the next lower values of C. This reconciliation is close enough to establish the Williams-Hazen formula for general design and testing purposes.

TABLE 4

Effect of Temperature Change Upon Friction Factor f of Smooth Pipe

Temp. °F.	Reynolds Number (R)	Friction Factor (f)	Percentage Change
40°	7,300	0.0336	109
60°	10,000	0.0309	100
80°	13,200	0.0287	93

TABLE 5

Effect of Temperature Change Upon Friction Factor f of Rough Pipe

Temp. °F.	Reynolds Number (R)	Friction Factor (f)	Percentage Change
40°	7,300,000	0.00849	105
60°	10,000,000	0.00810	100
80°	13,200,000	0.00779	96

Comparison of Formulas

Figure 1 shows the relative values of f for the Manning, Kutter (practically the same as in Manning), Fanning, Williams-Hazen and the R formulas. The Williams-Hazen values of f are for C equal to 100, 110, 120, 130, 140 and 150. The R values of f are for k (in feet) equal to 0.0004 and 0.00085, and a temperature of 50°F. The Manning (Kutter) values of f are for n equal uniformly at 0.013 and 0.015. The Fanning values of f are as listed in his *Treatise* (3). All are in terms of a velocity of 3 fps.

No reconciliation can be found in terms of a uniform value of n for the Manning (Kutter) formula with the Williams-Hazen formula. No recon-

Conclusion

This reconciliation seems to support the general conclusions that, for pipeline designing, the Manning (Kutter) formula and the Fanning values of f should be abandoned, and that the Williams-Hazen formula should be established as the best formula in comparison with the R parameter. The Williams-Hazen formula in terms of its several values of C has a very concrete meaning in the minds of most engineers, Public Service Commissioners, city officials and lawyers. If a slight deviation can be made, as for pipe from 4 to 18 in., there is no reason for its abandonment. The objection to the Williams-Hazen formula is that, in its usual form, C is

dimensional. This makes it difficult to take *direct* account of the effect of pipe roughness on the value of Williams-Hazen coefficients. Also, in its present form it is difficult to use without aid by tables and other devices. By translating the different values of the Williams-Hazen C into values of f in the Darcy formula, both of these objections are eliminated. At the same time, the use of these values of C and the great advantages they offer are retained. The value of the developments in establishing the **R** parameter is realized and, by the use of the Rouse chart (Fig. 2) and Tables 1 and 2, it is believed that the advantages of both systems may be fully realized.

References

1. ROUSE, HUNTER. Evaluation of Boundary Roughness. Proc. Second Hydraulic Conf., Bul. 27, Univ. of Iowa Studies in Engineering (1943), p. 105.

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3. FANNING, J. T. *A Treatise on Hydraulic and Water Supply Engineering.* D. Van Nostrand Co., New York (1906).

List of Symbols

A —Area of pipe (in square feet)

C —Coefficient in Chezy formula

C_{W-H}—Coefficient in Williams-Hazen formula*

D —Diameter of pipe (in feet)

d —Diameter of pipe (in inches)

f —Friction factor in Darcy formula

g —Acceleration of gravity (taken as 32.16 ft. per sec.²)

H_f —Friction head loss in 100 ft. of pipe

K —Multiplying factor corresponding to various values of Williams-Hazen C and Darcy f.

k —Height of surface roughness or some linear dimension representing average height, form and distribution of such projections (used in **R** parameter)

L —Length of pipe in feet

n —Coefficient of roughness in Manning and Kutter formulas

Q —Discharge (in cubic feet per second) $= AV$

R —Hydraulic radius of pipe $\left(\dfrac{D}{4}\right)$

R   —Reynolds number

r —Geometrical radius of pipe

s —Slope of pipe per foot (sine of slope angle)

V —Mean velocity (in feet per second)

ν(nu)—Kinematic viscosity

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* Where C_{W-H} is used in a direct statement in terms of the Williams-Hazen formula, it is referred to as C.

Abstracts of Water Works Literature

CHEMICAL ANALYSIS

Colorimetric Determination of Iron, Manganese, Phosphate, and Silicic Acid. W TEICHERT. Iva (Swedish), **17**: 135 ('46) Tests carried out to find rapid and accurate methods suited for boiler-water anal. of small amts. of above substances. Detns. of Fe, P_2O_5, and SiO_2 partly based on previous work, while new method found for Mn. Tests carried out in 100-ml. vessel in layer thicknesses of 34 mm. and with a BG7 color filter (bluish green) with max. light transmission between 4700 and 4800Å. In Fe detn. in quants. greater than 0.1 mg./l., 100 ml. of water used and 200 ml. for less than 0.1 mg./l. Add 10 ml. 5 N HCl and 5 ml. 3% $H_2O_2/100$ ml. sample and boil. After cooling to room temp. add 5 ml. 7.5 M NH_4CNS per 100 ml. sample. Extract immediately with amyl alc.-amyl acetate mixt. and det. light absorption immediately. Amts. present detd. by comparison with extinction E of sample soln. of known Fe content (between 0.005 and 0.008 mg.) and applying law of Beer. For detn. of Mn in quants. of less than 0.1 mg./l. add to 100 ml. of water sample 5 ml. 12 N H_2SO_4, 0.05 ml. 0.01 N Ag_2SO_4 soln., and 1 g. $(NH_4)_3S_2O_8$. Heat to boiling in flask covered with watch glass and keep boiling evenly for 20 min. After fast cooling to room temp. add 10 ml. of a 1:1 (by vol.) mixt. of 1% KI and 1% starch. Det. absorption 10–15 min. after addn. of KI-starch soln. Carry out 2 blank tests. Det. Mn content in sample either with calibration curve or arithmetically. Phosphate ion detd. in 100 ml. of water, at higher concn. in smaller quant. dild. to 100 ml. Add 5 ml. 12 N H_2SO_4 if yellow-colored $H_3[PO_4.12 MoO_3]$ is to be reduced to Mo blue by Rodinol (a photographic developer contg. p-aminophenol as reducing agent) or add 7.5

ml. of 12 N H_2SO_4 if Rullex (developer contg. substituted aminophenol) is used. Then after 3 min. add 5 ml. $(NH_4)_2MoO_4$ soln. (50 g./l.) and after 2 min. add 5 ml. of undild. developer. Stir until all liberated SO_2 is removed. Then sample has to stand 15 min. before absorption reaches const. value. Compare with standard. For detn. of SiO_2 add to 30 ml. of water sample 15 ml. 0.25 N HCl and 15 ml. $(NH_4)_2MoO_4$ soln. (100 g./l.). After 5 min. add 30 ml. of soln. of 170 g. Na_2SO_3 in 1 liter water and det. absorption exactly 1 min. after addn. of Na_2SO_3 soln. Since temp. affects velocity of development of blue coloration, measurements must be made at same temp. ($\pm 2°$). Measuring range of method is from 0 to 1.4 mg. SiO_2 per sample. Accuracy does not decrease with smaller samples dild. to 30 ml. Results agree within ± 0.05 mg. SiO_2. Comparative results of all 4 methods given in 16 tables and 11 graphs. — *C.A.*

Polarigraphic Determination of Sodium and Lithium in Natural Waters. A. A. REZNIKOV & A. S. S. SMAGINA. Trudy. Vsesoyuz. Kong. anal. Khim. (U.S.S.R.) **2**: 559 ('43). Study of polarigraphic detn. of sodium and lithium in natural waters presented. Expts. made to det. sodium in presence of potassium, lithium in presence of sodium and potassium, sodium and lithium in presence of other substances commonly found in natural waters, and sodium and lithium in natural waters of various compns. Results showed that when pure solns. of sodium salts used, concns. of solns. directly proportional to wave heights of sodium. In detg. sodium polarigraphically, max. error $\pm 3\%$. Interference with detn. of sodium caused by presence of cal-

cium, magnesium, iron and potassium ions which must, therefore, be removed or converted into complex ions before detn. made. Calcium, magnesium and iron removed by adding excess of tetramethylammonium hydroxide, which also acts as indifferent electrolyte in polarigraphic detn. In procedure recommended, given vol. of sample contg. sodium, potassium, calcium, magnesium and iron treated with equal vol. of magnesium dipicrylamine to ppt. potassium; after interval of 20–30 min., amt. of 0.1 to 0.2*N* tetramethylammonium hydroxide just in excess of that required to ppt. calcium, magnesium and iron added to aliquot portion of soln. After 30 min., aliquot portion of clear soln. taken and content of sodium detd. polarigraphically. Lithium must be separated from sodium and potassium before it can be detd. polarigraphically. Method for separation of lithium, based on fact that lithium chloride soluble in acetone, described.— *W.P.R.*

Bromide Content of Underground Waters. I. Determination and Occurrence of Traces of Bromide in Water. G. U. HOUGHTON. J. Soc. Chem. Ind. (Br.), **65**: 277 ('46). Volumetric method of d'Ans and Höfer and colorimetric phenol red procedure of Stenger and Kolthoff compared. Former, slightly modified, gave best results. In modified procedure, sample contg. 50–1000 γ of Br taken. Fe, if present, removed by evapg. sample to dryness and extending residue with hot water. Filtered extract or original sample in absence of Fe, evapd. to 2–3 ml., and 2 ml. phosphate buffer (22.5 g. KH_2PO_4 and 90 ml. N NaOH dild. to 200 ml.), 4 ml. NaCl soln. (25 g. NaCl/100 ml.), and 10 ml. Cl water (1 ml. equiv. to 2.0 mg. available Cl) were added. After refluxing for 15 min. 2 ml. NaCOOH (10 g./100 ml.) added, and soln. heated for 5 min., cooled to 25°, and treated with 3 drops NH_4 molybdate (10 g./100 ml.), 1 ml. KI (5 g./100 ml.), and 5 ml. HCl (25 ml. concd. HCl in 100 ml.). After standing in dark for 5 min., liberated I was titrated with 0.001 N thiosulfate. Qual. tests showed absence of bromate in samples analyzed. In most cases Cl/Br ratio found in 30 well water samples approximated that found in sea water (300:1). Range of Br content 0.026–2.26 ppm. **II. Chlorination of Water Containing Free Ammonia and Naturally Occurring Bromide.** Ibid., 324. With acid o-t. test for free Cl, color completely developed in 60 sec. when over 0.5 ppm. of Br also present. The Laux

flash test for distinguishing between free Cl and chloramines cannot be applied in presence of Br. Br does not interfere in neutral o-t. test or in Palin procedure using p-aminodimethylaniline. Br found partially to offset lag in rate of sterilization due to NH_3. In absence of org. matter 1 ppm. Br increased rate of sterilization by chloramine markedly, while in some cases 0.25 ppm. Br had appreciable effect. On addn. of free Br to water contg. NH_3 curve similar to break-point curve for Cl obtained; thus indicates that bromamines formed in dil. aq. soln.—*C.A.*

Volumetric Method for Determining Sulfate in Water. D. C. AZNAR. Farm. nueva (It.), **7**: 412 ('42); Chem. Zentr. (Ger.), 2: 2508 ('42). In method for detg. sulfate in water, 100 ml. of water heated and 20 ml. of soln. of barium chloride contg. 0.305% $BaCl_2$, $2H_2O$ added. Next are added 5–6 g. of sodium acetate and 20 ml. of a 0.18379% soln. of potassium dichromate. Mixt. filtered; 200 ml. of filtrate refiltered and first part of filtrate rejected. To 100 ml. of remainder of filtrate are added 1 g. of potassium iodide and 10 ml. of hydrochloric acid; soln. titrated against sodium thiosulfate.—*W.P.R.*

A Simplified Method for Potentiometric Determination of Sulfates in Natural Waters. N. I. VOROB'EV. Zavodskaya Lab. (U.S. S.R.), **12**: 375 ('46). Method based on potentiometric titration with K_2CrO_4 of excess Ba^{++} remaining after pptn. of sulfates. Titration carried out with air electrode (Pt electrode satd. with air) which reacts rapidly to any changes in pH value. During titration of excess Ba^{++} with CrO_4^{--}, free CrO_4^{--} appears after pptn. of all Ba^{++}, and reacts thus: $2CrO_4^{--} + 2H^+ = 2HCrO_4^- = Cr_2O_7^{--} + H_2O$. Decrease in concn. of H^+ at equiv. point manifested by jump in potential of air electrode. Exptl. error did not exceed 1% in all cases when quant. of SO_4^{--} not less than 5 mg. (50–100 mg./l.). Sometimes error reached 5% when quant. of SO_4^{--} in sample soln. less than 5 mg.—*C.A.*

Titrimetric Determination of Sulfate in Natural Waters and Soil Extracts. E. C. CANTINO. Soil Sci., **61**: 361 ('46). Empirical method given for detn. of sulfate in water soln. Sulfate pptd. in acid soln. with $BaCrO_4$; excess Ba elimd. by making soln. alk. Remaining chromate detd. by titrating with thiosulfate. Sulfate content ascertained by comparison with std. curve giving mg. of

sulfate as function of ml. of thiosulfate. Adherence to exact procedure emphasized. When vol. of indicator used increased from 2 to 10 drops, deviation of sulfate value from original content increases from 0.3% to 8.2%. With increase from 100 ml. of wash water to 200 ml., deviation from original content increases from 2.8% to 4.1%. Anals. of synthetic solns. show that ions Na, K, Ca, Mg, and nitrate do not seriously interfere in sulfate detn. With Na, K, and nitrate ions present in excess of 100 mg., and Ca and Mg ions present to that extent, deviation from original sulfate content zero in soln. contg. originally 6.4 mg. of sulfate, and deviation 0.8% in soln. contg. originally 25.5 mg. of sulfate. Data for anals. of 5 samples of water show that deviation from original sulfate content, detd. gravimetrically, ranges from 0.2% to 1.2%.— *C.A.*

Determinations of Chlorides in Water. W. SCHNEEBELI & M. STAUB. Mitt. Lebensm. Hyg. (Swiss), **36**: 20 ('45). Colorimetric method for serial detns. of chlorides in drinking and waste water described which gives better results than customary titrimetric method. Excess of $AgNO_3$ added to water which contains 1 ml. K_2CrO_4 per 100 ml. water. Red-brown coloration which develops compared with color of known test solns. — *C.A.*

Rapid Method for the Determination of Oxygen in Water. A. G. KOBLYANSKII. J. Applied Chem. (U.S.S.R.) **18**: 725 ('45). Water to be tested (10 ml.) introduced into 13–14 ml. test tube, few drops of Mohr's salt soln. (0.02 N Fe, 0.1 N H_2SO_4) added, and soln. covered with 1 ml. petr. ether to exclude O, and finally 1 ml. of a buffer soln. (satd. aq. NH_4Cl:concd. aq. NH_3 = 1:1) added. After 1 min. 2–3 drops of satd. alc. soln. of dimethylglyoxime added. Bright red color indicates that too much Fe^{++} was added and test repeated with less Mohr's salt soln. until exact amt. of Fe^{++} required detd. Correction to be applied for O contained in solns. used amts. to about 0.3–0.6 drops of Mohr's salt soln. for an O content of 0.5–4 mg./l. Method less accurate than other known methods, but can be carried out in 3–4 min.— *C.A.*

Twenty Years' Experience With the Dissolved-Oxygen Absorption Test in China. W. E. ABBOTT. J. Soc. Chem. Ind. (Br.), **65**: 87 ('46). For simplicity suggested that 3-

day incubation at 20°C. be used, or alternatively 2 days at 30°C. Although course of oxidation of C variable at const. temp., below 20°C. it can sometimes be represented by an autocatalytic type equation.— *C.A.*

Method for Calcium-Sequestering Value of Phosphate Water Conditioners. B. C. HAFFORD, FRED LEONARD & R. W. CUMMINS. Ind. Eng. Chem.—Anal. Ed. **18**: 411 ('46). A 4-g. sample of phosphate dild. to 250 ml. and filtered. A 25-ml. aliquot adjusted to pH 10 with 0.1 N NaOH and dild. to 55 ml. in optical cell. This soln. titrated with std. $CaCl_2$ (2.5 g. Ca per l.). Percentage transmittance detd. and end-point detd. from intersection of 2 straight lines on plot of percentage transmittance vs. ml. $CaCl_2$. Ca value (g. Ca sequestered per 100 g. sample) calcd. from ml. of standard $CaCl_2$ required to just start pptn. pH and sample size have influence on results, so procedure must be rigidly standardized. Method has limit of uncertainty of ±0.4 for Na tripolyphosphate having Ca value of 10.4—*C.A.*

The Application of Cacotheline in Volumetric Analysis. M. L. KUCHMENT & A. I. GENGRINOVICH. Zavodskaya Lab. (U.S.S.R.) **11**: 267 ('45). Use of cacotheline, nitro-derivative of brucine, as an indicator in detn. of calcium and of trivalent iron discussed. *I. Detn. of calcium salts by direct titration with sodium oxalate.* In procedure recommended for detn. of calcium, 1 ml. of satd. aqueous soln. of cacotheline and 1 drop of satd. aqueous soln. of ferrous salt added to sample contg. calcium, and soln. then titrated with 0.1 N soln. of sodium oxalate until violet color appears. Percentage error of detns. made by this method varied from ±0.15 to ±0.67. More accurate results obtained if blank titration first carried out. If calcium salt dissolved in dil. acetic acid, detn. of calcium can be effected in presence of magnesium. *II. Direct detn. of salts of trivalent iron by titration with stannous chloride soln.* In procedure recommended for detn. of trivalent iron, sample contg. ferric ions dild. with equal vol. of 4 N hydrochloric acid, 1 ml. of satd. aqueous soln. of cacotheline added and mixt., after it has been heated to boiling point, titrated with soln. of stannous chloride (prepd. by dissolving 30 g. of stannous chloride in mixt. contg. 300 ml. of concd. hydrochloric acid and 700 ml. of water) until violet color appears. Since reaction slow and incomplete in cold solns., titration must be

carried out while soln. still hot. Percentage error of detns. varied from ± 0.03 to ± 0.26—*W.P.R.*

The Reaction Velocity of Ion Exchange. F. C. NACHOD & W. WOOD. J. Am. Chem. Soc. **66**: 1380 ('44); **67**: 629 ('45). Study of reaction veloc. and mechanism of ion exchange presented. In first series of expts., rates of exchange of sodium and hydrogen ions by various natural and synthetic cation-exchange materials, and of chloride ions by some resinous anion-exchange materials measured. Results, tabulated and expressed graphically, showed that reactions second order, bimolecular reactions and that, in calcg. reaction const., concns. could be substituted for activities. Rate of exchange of anions found very much slower than of cations. In series of expts. on cation exchange, reactions all carried out at temp. of 27°C. and in every case anion Cl^- used. Different rates of reaction observed for various commercial ion-exchange materials even when exptl. conditions unchanged. From study of effect of temp. on rate of exchange with sulfonated carbonaceous exchange material, found that at 60°C. rate of reaction same as that at 27°C., but at 0°C.

reaction proceeded more slowly. Second series of expts. made to det. effects of different anions and cations on rate of cation exchange. Number of hydrogen-ion-exchange reactions studied in which cations were Na^+ in each case and anions were Cl^-, SO_4^{--}, NO_3^-, HCO_3^-, $HCOO^-$ and CH_3COO^- respectively. Results showed that rate at which equil. approached same for different anions, though values obtained for exchange capac. very much higher with salts of weak acids than with salts of strong acids. Same exchange material then used to det. rate of exchange of hydrogen ions when anions were Cl^- and cations were Li^+, Na^+, Rb^+, Cs^+, Mg^{++}, Ca^{++}, Sr^{++} and Ba^{++} respectively. Found that cation-exchange capac. increased as charge on cation increased, but that rate of exchange greater for monovalent than for divalent cations. For cations in same periodic group, those with low atomic wts. exchanged at greater rate and had higher equil. consts. than those with high atomic wts. Other factors affecting reaction veloc., including rate of diffusion in and out of granules of exchange material and size of ions, discussed. Description of extpl. procedure adopted included.—*W.P.R.*

SWIMMING POOLS

Purification of Swimming Pool Water by Continuous Circulation. O. L. RENSONNET. Tech. l' Eau (Belg.) **1**: 17 ('47). Description of various methods used and comprising prefiltration, pumps for recirculation, coagulation with alum, rapid sand filters, backwashing, aeration, sterilization, reheating equip. and flow control instruments.—*W. Rudolfs.*

Quality and Treatment of Water for Swimming Pools. E. LECLERCK. Tech. l' Eau (Belg.) **1**: 3 ('47). Requirements: an object must be seen in 3 m. of water, corresponding to 1 ppm. SiO_2, color absent, chlorine residual 0.1 to 0.5 ppm., less than 200 organisms per ml., *Esch. coli* absent in 100 ml. In open basins water must circulate 2 or 3 times a week. Closed pools should have min. of 200 l. pure water per bather, circulation every 8 hr. for small pools, and every 10 hr. large for pools. Treatment by filtration, aeration, sterilization and reheating. Small pools used for children contain more bacteria, hence require more supervision and control.—*W. Rudolfs.*

Legislation, Hygiene and Prophylaxy of Swimming Pools, Showers, and Baths. A. DE WEVER. Tech. l' Eau (Belg.) **1**: 13 ('47). General rules and regulations concerning operation and use of pools and showers.—*W. Rudolfs.*

Results of Several Years' Observation of a Municipal Open-Air Bath in Vienna. E. HOFMANN. Gesundh.-Ing. (Ger.), **67**: 105 ('44). Observations made for 6 yr. on large open-air swimming bath in Vienna. There are 4 baths, with total capac. of about 5000 cu.m. Water, which is obtained from well, is recirculated in about 18 hr. in largest bath, and in about 16 hr. in each of 3 smaller baths. Every day 10% of make-up water added. Bath water filtered and chlorinated. Chlorine added varies from 0.9 to 1.5 g./cu.m. of water per hr., according to no. of bathers. Water for drinking and for shower baths taken from town's supply. Water for shower baths stored in open tank where warmed by sun. Copper sulfate in dose of 9 kg./1000 cu.m. of water used to control algal growths.

In routine bact. examn. samples examd. as soon as possible. To investigate effect of keeping samples, 1 series inoculated on gelatin plates immediately after collection; another series inoculated after being kept in lab. for 2 hr. Cultures examd. after 9 days. When concn. of free chlorine more than 0.1 mg./l., nos. of bacteria smaller in samples which had been kept in lab., but with samples contg. less than 0.1 mg./l. growth of bacteria only temporarily checked, and after 7 days bact. counts about same in both series. It thus appeared that residual concn. of less than 0.1 mg. of chlorine per l. insufficient to reduce effectively no. of bacteria in bath water, and that, to avoid error, samples should be examd. as soon as possible. Detn. of chlorine demand of well water and of bath water before and after treatment showed that these values could not be correlated with amt. of chlorine necessary for adequate treatment of bath water. Detn. of free chlorine in bath water only satisfactory method of detg. chlorine required, and its effectiveness must be checked by bact. examn. Changes in chem. compn. of bath water during use examd. Content of ammonia found to increase when bathing load heavy and content of chlorine 0.03–0.04 mg./l.; with chlorine content of 0.1 mg./l. or more only traces of ammonia found even with heavy bathing load; this suggests that presence of ammonia could be used as indication of insufficient chlorination. Presence of nitrites on other hand of secondary importance as indication of condition of water. Efforts have been made to use concn. of urine or one of its constituents as measure of poln.; for this purpose detn. of permanganate demand not satisfactory as urea and other constituents incompletely oxidized by permanganate; increase in content of chloride also not satisfactory indication, as in chlorinated water chlorides may be formed during soln. of free chlorine in water. There is, however, during use of bath water, general increase in concn. of nitrate. Author found that during period of 54 days nitrate increased from 3.5–14 mg./l. In spite of low bact. counts, such a content of nitrate regarded as aesthetically undesirable and increase in nitrate over content in unused water of more than 10 mg./l. has been taken to indicate that bath should be refilled with fresh water. Comparative ests. of content of suspended solids in water obtained by sedimentation tests and by detg. amt. of water which would pass through cotton-wool filter pad before it became choked; these detns., made on water before and after passage through sand filters, used to check operation of filters. Concn. of org. matter in settleable solids increased rapidly with period of use of water and, especially in children's bath, large nos. of micro-organisms of animal and plant origin present. Examn. of sludge deposited in swimming bath showed that it consisted mainly of green algae and contained Chlorophyceae and chironomid larvae. As a whole investigations over 6 yr. showed that there was much variation in rate at which poln. accumulated in water during periods of use. Poln. and bact. counts increased most rapidly in children's bath and it it is desirable that, in constructing baths, children's bath should always be separate so that water can be changed more often than in larger baths.—*W.P.R.*

A New Way to Get Uniform Circulation. COURTNEY OGBORN. Beach & Pool **17**: 8: 5 (Aug. '43). Conventional, treated water inlets as installed to provide circulation in indoor swimming pools overlook several factors of physical reaction, thus decreasing operation eff. Proposes series of 2 or 3 outlets across shallow end close to bottom and similar series across deep end with reduced vol. of treated water dischg. In addn., several small outlets provided along each side, close to bottom. Such installation involves slightly larger initial expense over conventional design but offset by following advantages: (1) Provides pos. movement of all water from both ends toward pool outlet. (2) Takes advantage of warm water tendency to rise thus distributing treated water through all pool strata. (3) Current along bottom following slope will tend to carry heavy, loose dirt particles toward outlet, lessening necessary hand scrubbing. (4) Water splashed into scum gutters well mixed and contains min. percentage of fresh water. Model pool of above design proved advantages when operated at different temps., pressures and vols. of flow.—*Ralph E. Noble.*

Methods of Water Sterilization. DOUGLAS CORK. Conf. of Swimming Pool Operators, Ill. Dept. Health, sponsored by Chicago Bd. of Education (Apr. 28, '43). Ideal sterilizing agent for swimming pool water must effectively kill and inhibit polg. organisms; be non-toxic and non-irritative as used, to human beings; non-corrosive; easily applied and effective concn. of it built up in short time; stable; easily controlled; inexpensive; safe to

use; algae inhibitor; and available. *Types of water sterilization* with advantages and disadvantages: (1) *Chlorine powder*, applied by bagging. Good sterilizer; non-toxic; easily applied; relatively inexpensive; equip. unnecessary; and safe. Irritant; corrosive; unstable; residual varies; not algaecide as used; and scarce. *Chlorine gas*, applied by pulsator. Good sterilizer; non-toxic; easily applied and controlled. Irritant; unstable; corrosive; expensive due to high first equip. cost; not algaecide as used; *dangerous* as poison gas under h-p.; and scarce. *Chlorine liquid*, hypochlorite, applied by pumping: Good sterilizer; non-toxic; relatively stable and non-irritant; non-corrosive; easily applied; easily controlled; inexpensive; and safe. Not algaecide as used; and scarce. *Sodium hypochlorite*, electrolytic cell. Good sterilizer; non-toxic; relatively stable and non-irritant; easily controlled; plentiful, using only salt and elec.; safe. While easily applied, must be slow due to no overload capac.; expensive due to first equip. high cost; not algaecide as used. *Liquid bromine*, applied by suction. Effective sterilizer; non-toxic; non-irritant; non-corrosive; easily and rapidly applied; stable reading may not be obtained with o-t. but water will remain in good condition, as proved by lab. test showing continued presence of sterilizer; easily controlled; inexpensive; available and easily obtained; dangerous only to careless operator. Bromine not a gas or under pressure but slowly vaporizing liq., caustic in pure form, causing bad burns. Empty glass containers must be changed with care by operator.—*Ralph E. Noble.*

Swimming Pool Sanitation. ANON. Calif.'s Health **1**: 6, 28 (July 31, Aug. 31, '43). Although exact manner of poliomyelitis spread unknown, pub. interest always focused on swimming during outbreak. Imperative that pool operators heed health officers' advice and that high san. std. be maintd. at pools remaining open: All swimmers, particularly children, should avoid diving and underwater swimming. Swim with nose and mouth above water. Blowing nostrils, spitting in pool and on sidewalks and "bellowing" shall be prohibited as much as possible. Encourage and require shower baths before entering pool. *Scum Gutters*: Maint. high water level to float scum and sputum continuously to sewer. Keep gutters clean, sputum and scum off water as much as possible. If gutter drains inadequate, install more. Disinfect gutters as in *Cleaning Floors and Walks*: Wash down 2 or 3 times daily, sprinkle with Cl_2 soln. twice daily. Use 4 oz. of any Cl_2 chem. in 5 gal. of water. *Suits and Towels*: Thoroughly wash, rinse and dry in sun where possible before re-using. *Excluding Sick Persons*: Keep out those with symptoms of colds, inflamed eyes or fever. Prevent children and others from remaining in water to point of chilling or fatigue. *Changing Water*: Increase changing frequency wherever feasible, especially following heavy patronage, e.g., with fill-and-draw pools, change water daily on weekends and holiday periods, and every other day during week. Pools equipped with complete disinfection, filters and recirculating pumps should also increase changing frequency as fully as possible. *Chlorination*: Not certain that Cl_2 kills poliomyelitis virus. Nevertheless, maint. not less than 0.2 ppm. If customary 0.5 ppm. causes eye sting, reduce it. During epidemic make Cl_2 tests 3 or 4 times daily at 5 or 6 different points using o-t. soln. Maint. adequate supply of Cl_2, test materials and o-t.—*Ralph E. Noble.*

WATER WORKS ANNUAL REPORTS

10th Annual Report (1945) Little Rock (Ark.) Munic. Water Works. 3 man board. Pop. of city 102,200; pop. served, 128,400. Per capita production; 72 gpd.; sales 61 gpd.; 21,662 customers. Income $880,320. Fixed assets $7,488,466 and cash reserve $885,268 offset by capital liabilities and funded reserves of $6,014,932. Surface water supply, watershed of 43 sq.mi. normal pptn. of 48″, normal run-off of 14 bil.gal., storage reservoir of 14 bil.gal. A 39″ pipeline 35 mi. long. capacity 25 mgd., delivers water to 92-mil.gal.

auxiliary storage reservoir and 15-mgd. filtration plant. Water production avgd. 11.33 mgd. with max. day of 15.11 mil.gal. Total hardness of water delivered 30 ppm. Electric pumping station rated capac. 12.75 mgd. Distr. system 125 mi. of 4″-24″ mains and 123 mi. of 1″-3″ mains deliver the water to 1004 hydrants and 21,526 meters. 6% rate reduction to 99% of customers effective Nov. '45. Cost per 1000 gal. to domestic customers: '36, 42.3¢; '45, 35.0¢. Fish rearing pond stocked in May produced

50% yield in Oct. Free residual chlorination for 6 yr. has restored most of capac. of supply main lost by organic growth. Plans for expansion of distr. system totaling $375,000 are well under way.—*O. R. Elting.*

Pasadena (Calif.) Water Dept. Annual Report (for Year Ending June 30, 1946). The dept. organized in '12 by the purchase of 3 water companies; 33 other systems acquired. Estd. pop. served 120,600; water consumption 16.7 mgd. or 138.5 gpd./capita, exceeding previous max. by 15.5%. Distr. system 375 mi. of 2-36" mains, 1829 hydrants and 31,414 services. 38% of the water obtained from wells, 19% by gravity and 43% from Colorado River by purchase from Metropolitan Water Dist. Gross revenue $1,303,359, gain of $156,329 over previous year. Operating and maint. expenses $973,376, increase of $148,-046. Payment into general city fund $60,-730. Fixed assets $7,913,200; depreciation reserve $3,283,456. Total liabilities $160,-378. Surplus $7,191,700.—*O. R. Elting.*

16th Annual Report (for Year Ending Dec. 31, 1945) Water Bureau, Metropolitan Dist., Hartford (Conn). Organized '29. Dist. includes Hartford and 7 adjoining municipalities. Estd. population served 315,000, 7-day max. consumption 31.24; max. month 29.61 mgd.; yearly avg. 29.45 mgd., a decrease of 3.6% from '44. Gravity supply. Distr. of revenue dollar: supply 4.4¢, purif. 3.7¢, distr. 8.1¢, accounting 3.5¢, admin. 13.9¢, taxes 1.6¢, depn. 17.6¢, fixed charges 47.2¢. Distr. system of 613 mi. serves 39,135 services (38,357 metered) and 4008 hydrants. Gross revenue $1,614,313. Operating expense $841,537. Fixed capital $30,606,053; bonded debt $10,034,000; net worth $13,539,156. Consumption in excess of 28 mgd. occurred on 229 days as against 238 days in '44.—*O. R. Elting.*

Annual Report Water Department, Oak Park (Ill.), 1946. Water purchased from city of Chicago on metered basis delivered to the village through 5—12" meters. 3 other connections assure protection for supply. Pump station houses 8 motor-driven pumps, combined capac. of 24 mgd., boosting pressures an avg. of 25 psi. Storage reservoir 5 mil.gal. Estd. pop. 69,000; consumption 5.91 mgd. 107.4 mi. of mains supply 12,062 meters and 1135 hydrants. System 100% metered, water sold 88.8% of total. Total income $453,123; expense; purchase of water

$159,492; operation and maint. $107,899; interest and principal $6,667; depn. $36,498; transferred to fire funds $137,000; net gain $5,567. Fixed assets: original $1,264,780; less depn. $213,336; current assets $290,076. Liabilities-bonds and deposit funds $55,271. Net worth (assets over liabilities) $481,935. Immediate $400,000 improvement of distr. system is planned. Water waste survey by Pitometer Co. discovered leakage of 0.477 mgd. mostly on old galvanized iron services. Unaccounted flow reduced from 14.6 to 11.1%.—*O. R. Elting.*

Des Moines (Iowa) Water Works Report, 1946. Operates under a 5-man Bd. of Trustees. Pop. 181,112; consumption 17.95 mgd. or 99.1 gpd. per capita. Water under pressure of 38 to 118 psi. delivered through 438 mi. of 4" to 36" mains (68% 8") to 3,758 hydrants and to 41,063 services, 99.5% metered. Metered billed 81% of water pumped. Gross income $1,083,558; operation and maintenance $477,322; net income $183,235; depn. $129,123; interest and sinking fund $293,877. Plant less depn. $7,535,-942; total assets $8,987,103. City's equity $5,156,254. Pumping max. 36.5 mgd.; min. 7.0 mgd.; avg. 17.95 mgd. Coal 15.8% ash; 9,230 Btu. as fired. Evapn. ratio 5.62, boiler and stoker eff. 66.2% station steam duty 114.9, over-all thermal eff. 8.98%. Rainfall 33.24", 1.20" above normal, air temp. avg. 50°F., max. 87°, min. 0°. Water temp. avg. 56°F., max. 73°, min. 41°.—*O. R. Elting.*

92nd Report New Orleans (La.) Sewerage and Water Board, 1945. Bd. of 6 city officials, 7 citizens elected for 12 yr. with overlapping terms supervise sewage, water works and drainage systems of city. Water consumption increased from 60.8 mgd. in '41 to 79.4 mgd. in '45. 60% of '45 water revenue-producing. Increased pumpage of sewage reqd. Carrollton plant met demand, but Algiers Plant heavily taxed. Recently completed addn. to latter will greatly relieve situation. Pension system established in '42. Board contributes 3% of payroll. New constr. costs for sewers, water works and drainage met by taxation; operation and maint. by water rates and budget by city for operation of drainage system, latter does not meet requirement and some income is contributed by water works and sewage funds. Money available for new constr. in 1945 $1,395,000. Estd. total expenditure of $12,-000,000 by end of '49. Fact that the source

which accounts for 60% of constr. fund ceases in 1950 indicates need for revised financial legislation. Total water, sewer and drainage assets $79,887,474. Outstanding bonds and current liabilities $16,701,659; water works and sewage operation income $2,696,515; expense $1,526,491. 94,469 services, 92,311 metered, 866 mi. 2″–48″ water mains. Avg. for (a) river (b) filtered waters: turbidity (a) 555, (b) 0 ppm.; alkalinity (a) 94, (b) 35 ppm.; incrustants (a) 32, (b) 36 ppm.; bacteria 37°C. Agar (a) 42,800, (b) 3 per ml.—*O. R. Elting.*

53rd Annual Report (Year Ending Sept. 30, 1946). Munic. Service Com., Wyandotte (Mich.). Pop. 32,000. Comrs. (appointed by mayor and confirmed by council) comprise 5-man bd. operating elec. and water utilities. Elec. Div. net income $290,043 after deducting all charges including depn. Dividend 20% of annual bill paid customers. Street lighting charge reduced from $31,000 to $2,000. Elec. plant, debt free, depn. value $1,624,090; extension fund' of $956,411. Consumer cost: residence 2.46¢, commercial 2.82¢, power 2.27¢ per kwhr. subject to 10% dividend. Dept. collects 3% state sales tax on elec. energy and the 4.3¢ per 1000 gal. of water used Sewage Disposal Tax for County Road Comrs. Smoke abatement and $1,250,-000 plant extension planned by Elec. Div. Plant capac. 21,600 kva.; power generated 44,036,000 kwhr.; 9,476 customers. Water Div. net income $27,229 after deducting all charges including depn. Depd. plant $1,283,-590, investments—$298,776. Debt $457,919; income $182,304. Expenses (%) pumping 11.1, purif. 17.4, distr. 24.0, office and admin. 7.9, interest 12.1, other expense 12.6, surplus 14.9. Operating revenue $21.49 per customer. Consumption 3.64 mgd. or 112.9 gpd. per capita; max. rate 6 mgd. Plant: 6—1 mgd. rapid sand filters, 1.4 mil.gal. underground and 0.5 mil.gal. el. storage. Pump capac. 14.8 mgd. Distr. system 92.7 mi. of mains, 756 hydrants, 7848 services. City plans tunnel to Canadian waters for better raw water supply. 77.45% water delivered to meters.—*O. R. Elting.*

Mt. Vernon (N.Y.) Board of Water Supply. Annual Report, 1946. Water obtained from New York City at $105 per mil.gal. Pop. 67,362 ('40); consumption 5.44 mgd. or 80.8 gpd. per capita. Water sold—90% of purchased water. 9488 services; 100% metered; 100 mi. mains; 1049 fire hydrants. Receipts $489,330. Expenditures—operation and maint. $289,372; capital expense $77,854; addition and betterments $30,000; surplus $92,104; bonds outstanding $624,000. Original plant value $3,093,667.—*O. R. Elting.*

Erie (Pa.) 79th Annual Report (1945) of Bureau of Water. Pop. 135,000; served 133,000. 28,499 services, 4.8% metered. Consumption 32.74 mgd., 246 gpd./capita, 302 mi. mains; 1,634 hydrants. Cost, collecting, purifying and pumping (including depn.) $29.63 per mil.gal. Income $829,495; expenditure exclusive of depn. $708,606; fixed assets (depd.) $10,042,804; cash $547,-748; bonds outstanding $911,000. Lake Erie water. Chestnut St. plant 17,641' of 60″ intake; 24 mil.gal. settling basin; 3–20 mgd. low-lift pumps; 32 mgd. filter plant; high-lift pump 60 mgd. total capac. West plant 8745' of 72″ intake; 34 mgd. low-lift sta.; 24 mgd. filtration plant; 32 mgd. high-lift pump capac. Two service dists. with 33 mil.gal. and 10 mil.gal. storage. Two standpipes of 440,000 and 400,000 gal. with booster stations serve outlying districts.—*O. R. Elting.*

Green Bay (Wis.) Water Dept., Report for 1946. Five-man Bd. of Comrs. Mains 134 mi.; 11,208 metered services; 762 hydrants. Bonded debt $617,000. Avg. consumption 4.59 mgd., 99 gpd. per capita, 86.8% water sold. Pumpage greatest in history. Pressures could not be maintd. during peak demand. Bids received for drilling new 24″ well. Probably not available for '47 peak. Two existing pumps to be lowered to prevent breaking suction during peak pumping. No substantial increase in yield of well obtained by acidizing.—*O. R. Elting.*

Potomac River Basin Commission. Fifth Annual Report (for Year Ending June 30, 1946). Commission of 18 members, 3 each from Maryland, Pennsylvania, Virginia, West Virginia, Dist. of Columbia and the federal government to control and abate poln. of the waters within the basin. Com. apptd: (1) Technical Committee composed of Directors of the State Planning Boards and State San. Engrs. and like federal representatives; (2) Industrial Committee of representatives of industry within the basin. Com. does not supplant or supersede existing agencies but works through them, thus avoiding inherent dangers of centralized planning and control yet well-rounded basin-wide poln. control

program being formulated by various agencies. Principal accomplishment of the year was acceptance by states of criteria and zones of principal water use zones prepd. by Tech. Committee and approved by commission. These criteria provide yardstick for min. stds. for dischg. of wastes and are an indication of relative purity of the streams. Federal control bill appropd. $1,900,000 for completing Savage River Dam. Com. encourages formation of local regional planning groups. Studies made by com. on conservation of national resources. Only method of carrying forward the work of com. is through education. This best accomplished by greater participation of the states in activities of the Tech. Com. and by greatly extended publicity program. Expenditures for year $15,607.—*O. R. Elting.*

11th Biennial Report Bd. of Water Supply, Honolulu (T.H.) (1945–46). Consumption decreased, water levels decline and salt encroachment increased. Decreased revenue and increased operating costs and capital expense made increased water rates necessary. New rates $\frac{5}{8}''$ meter 0.75 per mo. plus 24¢/1000 gal. for first 25,000 gal./mo. '46 revenue $2,074,352. First cost of plant $17,595,690, depn. $5,417,794. Bonded debt $6,576,884. Drought '40–'46. 1945 second driest in 57 yr. Rainfall 64% of avg.; past 7 yr., longest drought on record, 82% of avg. Use in '45 52.4 mgd.; '46, 49.3 mgd. Pop. '40, 179,000; '46, 267,000. Future program (1) recharging tunnel into aquifers, (2) 10-mgd. pump (3) 2 underground pumping stations. Hardness 21–173 ppm.; 3 pressure service areas; 33 mil.gal. storage; 349 mi. mains; 2,338 hydrants; 28,200 services 100% metered; unaccounted water 7.8%. Report contains detailed data on salt encroachment studies.—*O. R. Elting.*

Brisbane Water Supply. Wtr. & Wtr. Eng. (Br.) **48**: 512 ('45). In section on water supply in annual report for '43–'44 of Brisbane City Council, stated that 7,783.4 mil.gal. of water supplied during year; increase of 13.36% over previous year. Chief source of supply is Brisbane R.; Lake Manchester, Somerset and Enoggera reservoirs provide addnl. sources of supply. About $\frac{1}{3}$ of all water supplied filtered through slow sand filters. To prevent growth of algae, copper sulfate applied almost continuously from Jan. to Mar. to water before filtration. Vol. of water filtered through rapid sand filters,

which have total capac. of 12 mgd., 5,063.73 mil.gal. All filtered water treated with chlorine and ammonia for disinfection and with soda ash or lime to control pH value. Avg. bact. count in 1-ml. samples of treated water examd. daily was 9 when source of water Brisbane R. and 8 when source Enoggera Res. Brackenbridge service reservoir put into operation in Jan. '44. Low-level water works being extended; 6 rapid filters, with total capac. of 18 mgd., and tank for filtered water under construction. When these filters completed, 4 of slow sand filters will be adapted for storage of filtered water. By this means capac. for storage will be increased to 7.2 mil.gal.—*W.P.R.*

The Water Supply of Auckland, New Zealand. Wtr. & Wtr. Eng. (Br.) **47**: 508 ('44). In annual report of Auckland, N. Z., City Water Works Dept. for year ended Mar. 31, '44, A. D. Mead stated that total amt. of water supplied in '43–'44 was 5.189 mil.gal., equiv. to 78.33 gpd. per capita. Succession of 7 abnormally dry months Nov. '42–May '43, coupled with increased military and indus. demands for water, necessitated use of auxiliary sources of supply and restrictions on consumption. Service reservoir (capac. 6 mil. gal.) on Mount Albert almost completed. Land has been acquired for service reservoir (capac. 1 mil.gal.) at Titirangi. Another reservoir (capac. 1 mil.gal.) being constructed at Birkenhead to supply North Shore; duplicate submerged main will be laid across tidal channel of harbor. Corrosion of 9-in. steel main occurred and main has been replaced largely by asbestos-cement pipes.—*W.P.R.*

Rand, South Africa Water Board Report (For Year Ending Mar. 31, '46). Board supplies water in bulk to Transvaal Chamber of Mines, the South African Railways Administration and 12 municipalities and villages covering area of 3980 sq.mi. with pop. of 718,000 Europeans and 1,138,000 non-Europeans; total 1,856,000. Avg. 66.40 mgd. (Imp.), '44 and '45 avgd. 57.78 and 63.60 mgd. Pop. of municipal areas 1,433,000; European, 634,000; non-European, 799,000. This pop. within an area of 628 sq.mi. supplied with avg. of 32.8 mgd., remainder going to gold mines and ry. plus 2.4 mgd. to minor consumers. Total avg. price of water in bulk was 3.3d per 1000 gal.; divided: pumping 1.5d, maint. 1.0d, purif. 0.8d. Source of supply diversion rights to 215 mgd. from Vaal R. and 10 mgd. from

various boreholes and wells. 29.225 mgd. from river to industrial users. Rainfall in Johannesburg 29.45″. Evapn. at Barrage 62.97″. Pipelines total 426 mi. with 16.38 mil.gal. storage at pumping sta. and 114.88 mil.gal. at various high points. System extends 36 mi. from the Vaal R. at Vereeniging to the Central Rand and 80 mi. along the Witwatersrand from Libanon on west to Nigel on east. Max. pressure on mains 550 psi. Project to increase the potable supply 20 mgd., to give total of 90 mgd., under way. Estd. cost £2,335,000; 21% over 1941 est. At Vereeniging Sta., project includes 15 mgd.

filter plant, two 32,000-lb./hr. steam boilers; two 20-mgd. elec.-driven centrifugal pumps; a 3500 cfm. blower for carbonation plant; revision of the primary sedimentation tank. At the Zwartkopjes Station two 20-mgd. elec.-driven centrifugal pumps and two 50,000 lb./per hour steam boilers to be installed. Four addnl. reservoirs with total capac. of 65 mil.gal. included in program. Board employs 350 Europeans and 1,279 natives. Cost of the plant to date approx. £11,242,000. Outstanding indebtedness £5,866,000 less a redemption fund of $2,294,000. —*O. R. Elting.*

CORROSION CONTROL

Rust Preventive Oils. G. D. Pilz & F. F. Farley. Ind. Eng. Chem.—Anal. Ed., **38**:601 ('46). Rust preventive oils, composed of polar org. compds. in mineral oil, have been employed extensively in film applications for temporary protection against rusting of iron and steel parts during mfg. operations, storage, shipment and use. Condensation of moisture in droplets on such oil-coated steel parts produces a dynamic system composed of water, oil film and metal. Study of contact angles formed by such a system, where a drop of water rests on horizontal oil-coated steel panel, has established relationship between contact angles and rust preventive ability. Mathematical anal. of forces involved in spreading of water drop on a rust preventive oil film has shown that equilibrium surface tensions of water and oil and their interfacial tension are major factors detg. magnitude of contact angle. These findings in agreement with theory of rust prevention which postulates orientation of polar additive at oil-metal interface and establishment thereby of a barrier to normal mode of entry of rusting agents—oxygen and water. Contact angles were measured by microscope fitted with goniometer eyepiece; employed in detg. that soly. in water is of prime importance among physical properties of rust preventive additives and have found application in controlling plant production of rust preventive oils.— *Ed.*

Electroplating Pipe Interiors. S. G. Bart. Steel, **118**:25:96 (June '24, '46). Technic has been developed for electrodeposition of predetermined thickness of nickel or other corrosion-resistant metals on inside surfaces

of pipe, tubing, fittings, etc., to produce smooth, ductile, pore-free deposit closely adhering to base metal throughout later processing. In one case, pipe was drawn down to such an extent that wall was only $\frac{1}{4}$ as thick as original, without rupture of coating. Used on pipe up to 18″ in diam. Process called Lectro-Clad. Used in wide variety of plants including power plants, coke and gas products plants, etc.—*Ed.*

Plastic Pipe and Fittings for Small Water Lines, Conveying of Chemical Solutions, etc. Am. Ry. Eng. Assn. 48, Bul. **462**:201. (Nov. '46) Use of plastic pipe and tubing in ry. water supply field not very extensive, reports indicating installations of about 2200′ of 1″, 1½″ and 2″ standard plastic pipe used in corrosive location. After 3 yr. service, pipe shows no pitting, either internal or external. Use in treating plants to handle copperas soln. indicates good conditions after 3½ yr. service. No serious displacement in the use of metals for water pipeline foreseen, but advantage of plastic pipe in counteracting corrosion trouble and handling acid chem. solns. warrants consideration.—*R. C. Bardwell.*

Protection of Iron and Steel. U. R. Evans. Metal Ind. (Br.), **67**:8:114 ('45). Commercial applications of non-ferrous metal coatings on new or rusted structures discussed. Proposed methods are: (1) spraying by aluminum, followed by ordinary painting; and (2) paint richly pigmented with zinc to constitute galvanized coat. In some instances such coats make contact with steel by partial reduction of rust to metal, thereby providing conducting bridges. Impractical to load linseed oil with

sufficient zinc dust even if other pigments are omitted; therefore plasticized polystrene soln. contg. zinc dust up to 95% zinc by weight which can be brush applied, and commercial chlorinated rubber paint possessing required zinc content substituted. Such paints reduce or prevent corrosion fatigue by mech. exclusion of corrosive or by electro-chem. protection. Lab. tests show that such paints on rusty steel give cathodic protection in sea water.—*Ed.*

The Effectiveness of Paint in Suppressing Galvanic Corrosion. G. W. SEAGREN, G. H. YOUNG & F. L. LaQUE. Corrosion, **II**:2:67 (June '46). Expts. at Kure Beach show that presence of galvanic or stray elec. currents from external sources means that painting only surfaces to be protected may be dangerous, in fact may even cause acceleration of corrosion at area of paint discontinuity. Safest practice is to paint both anodic and cathodic areas with best alkali-resistant paints or coatings available, taking care to avoid pinholes, uncoated edges and similar foci for localized galvanic attack. Data and illustrations of copper-steel couple test panels, and effect of painting cathodic areas at Kure Beach, given.—*Ed.*

Relationship Between the Anti-Corrosive Properties of Paint Films and Their Pigment Content. Fette u. Seifen (Ger.), **51**:134 ('44); Paint, Oil Chem. Rev., **109**:18 (Jan. 10, '46); The Metals Rev., **19**: 4 (Apr. 8, '46). Pigments examd. included white lead and zinc oxide, lithium and titanium dioxide, antimony oxide, litharge, red lead, zinc yellow, talc and others. Vehicles consisted of variety of binders. Paints applied to iron and magnesium alloy panels and immersed in tap water and 3% salt soln. Effect of so-called anti-corrosive pigments minor in comparison with protection afforded by various vehicles tested.—*Ed.*

Relative Effectiveness of Cathodic Protection and Painting in Preventing Corrosion of the Interior of Steel (Water) Tanks. T. W. HISLIP JR. ET AL. Am. Ry. Eng. Assn. 48, Bul. **462**:196 (Nov. '46). Reports indicate that paint affords protection to interior of steel water tanks for not over 4 yr. at best, and requires several days' time out of service for cleaning and repainting. Cathodic protection in service about 10 years with tanks reported in good condition and no out-of-service time lost for installation. Prints included showing typical installation details. Com. concludes that cathodic protection, properly installed and maintd., has given more effective corrosion protection than paints applied to date and has added advantage that tank does not have to be taken out of service.—*R. C. Bardwell.*

Cathodic Protection. L. C. SECREST. Oil Gas J., **43**:3:82 ('44). Use of cathodic protection to prevent corrosion of pipeline laid in Colorado and Wyoming in '39 described. Pipe first treated with protective coating and wrapped with asbestos. Considered that if pipe could be maintd. at negative potential of 0.3 v. with respect to soil, there would be no corrosion. Wind-driven elec. generating units used. Positive electrode consisted of no. of pipes buried vertically or horizontally in soil. Bottom halves of horizontal pipes perforated; salt introduced into pipes and seeped into ground. No corrosion of pipeline has occurred so far.—*W.P.R.*

How Cathodic Protection Prevents Pipe and Tank Corrosion. Power Plant Eng., **50**:83 (June '46). Theory of cathodic protection; advantages; cathodic protection battery; prelim. steps to installation; conducting current survey for pipeline; test points; pipe-to-soil potential; current required for protection; ground beds; current sources; current density requirements for tanks; effect of ice on corrosion; record of protection system for tank; costs given.—*Ed.*

Magnesium as a Galvanic Anode. Some Factors Affect Its Performance. H. A. ROBINSON. Electrochem. Soc. Preprint 90 (Apr. 11–13, '46). Performance characteristics of magnesium anode have been studied with regard to effects of such variables as current density, anode compn., impurities, electrolyte pH, and electrolyte compn. Found that potential of magnesium anode sufficient for cathodic protection of pipelines, storage tanks, process equip., etc., with most naturally occurring electrolytes, and that both anode current eff. and uniformity of anode consumption improve with increasing current density. High purity magnesium-aluminum and magnesium-aluminum-zinc alloys perform more efficiently than commercially pure magnesium. Satd. solns. of calcium sulfate or magnesium sulfite provide most generally satisfactory electrolytes for magnesium anode operation.—*Ed.*

Use of Magnesium for Cathodic Protection of the Katy Pipeline. P. HART & O. OSBORN. Petrol. Engr., **17**:136 (Aug. '46). Highly successful application of magnesium for cathodic protection of the Dow Chemical Co.'s Katy pipeline on Texas Gulf Coast should be of exceptional interest to the corrosion engr. Cathodic protection as weapon in great battle against corrosion has always been intriguing subject to all engrs. Now after 6 yr. of extensive investigation, magnesium beckons as new and deadly ammunition for this weapon. Katy line 4-in. coated line, 82 mi. in length, extending inland from Dow Chemical Co.'s Freeport plant to Humble Oil and Refining Co.'s plant, 33 mi. west of Houston, Tex. This article shows how 96 magnesium anodes installed in 14 groups were employed in obtaining cathodic protection of this line.— *Ed.*

Cathodic Protection Stops (Internal Water) Tank Corrosion. ANON. Ry. Eng. & Maint., **42**:441 (Sept. '46). During the past 6½ yr., Chesapeake & Ohio Ry. installed cathodic protection in 48 of 148 steel water service tanks. With this method of elec. protection, no detrimental effects observed, interior corrosion below water level stopped and substantial savings reported, compared with cost of repainting the interiors of tanks below water level. 3 types of dry plate rectifiers used: MgS, CuS, and Se & CuO. Electrodes used have been wrought iron, steel and copper pipe, carbon sticks, platinum wire and a flexible glass hose filled with granulated carbon. Voltage varies as required to produce a necessary amperage of at least 3 amp. per 10,000 sq.ft. to be protected. Periodic inspection necessary to insure functioning.— *R. C. Bardwell.*

Polarization Studies of Inhibitor Action. R. D. MISCH & H. J. McDONALD. Am. Chem. Soc. 110th Meeting, Chicago (Sept. '46). Polarization behavior of corrosion inhibitors studied with modified polarization cell, originally developed by J. M. Bialosky, Armour Research Foundation. Cell consists of 2 parts, which hold soln. and are clamped on opposite sides of metal specimen. Current passed through system; one metal face becomes anodic and other cathodic. Potential at these surfaces measured for different current densities. Polarization curves obtained by plotting these values against current density. Influence of inhibitor structure shown in characteristic curves. Regular change in polarization characteristics found for homologous series. Exptl. differences in behavior of anodic and cathodic inhibitors shown. Importance of metal specimen shown for steel of different anals. Correlation found between polarization curves and stress corrosion susceptibility of various steels. Besides use of various inhibitors, metals and ions, influence of pH, temp. and soln. velocity studied. Depolarizing action of various ions on inhibitors shown. Comparison of effectiveness of some common inorg. and org. inhibitors at various concns. also made. Value of polarization cell in evaluating inhibitors discussed.— *Ed.*

Corrosion of Aluminum Pipes. H. LAFUMA. Inst. Tech. Batiment. Trav. Publ., Circ. Ser. G. (Fr.), No. 6 ('43). Tensile strength and final elongation of tubes of pure aluminum and aluminum alloys detd. after they had been embedded in Portland cement, slag cement, gypsum, and lime mortar and exposed to dry and moist air or water. Results described of corrosion tests in distd. and tap water, 0.1% soln. of sodium chloride, 0.05% soln. of calcium sulfate and very dil. soln. of sodium hypochlorite. Conclusions are drawn regarding applicability of aluminum pipes for water and city gas.— *Ed.*

On the Influence of Surface Treatment of Pure and Super-Pure Aluminum Components, With Special Reference to Water Pipes. H. WOLF & H. NEUNZIG. Aluminum, **26**:1:17 ('44). Tubes of pure and super-pure aluminum treated by various commercial protective processes, and by pickling for various times and at different temps. in 10% caustic soda. Then subjected for periods of 8–12 mo. to running water. Results of exposure to water given in full and illustrated by photographs. Influence of various protective treatments discussed. Purity of aluminum without marked effect.— *Ed.*

Internal Tubing Caliper. P. E. CHANEY. Petrol. Engr., **17**:7:122 (Apr. '46). Design, mechanism and operation of Chaney-Barnes tubing caliper, used to measure internal corrosion in tubing and well head fittings of gas-condensate wells, described and illustrated. Calipering accomplished by means of 6 or more independently operating lever arms, to outer ends of which are attached small wheels or rollers to contact tubing wall. Each lever arm provided with spring to urge feeler wheel outward against the tubing wall. Inner arms of levers contact a polishing steel plate on end of stylus rod.— *Ed.*

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N. T. Veatch, President 1947–1948
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